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FUTURE

ISSUE 123

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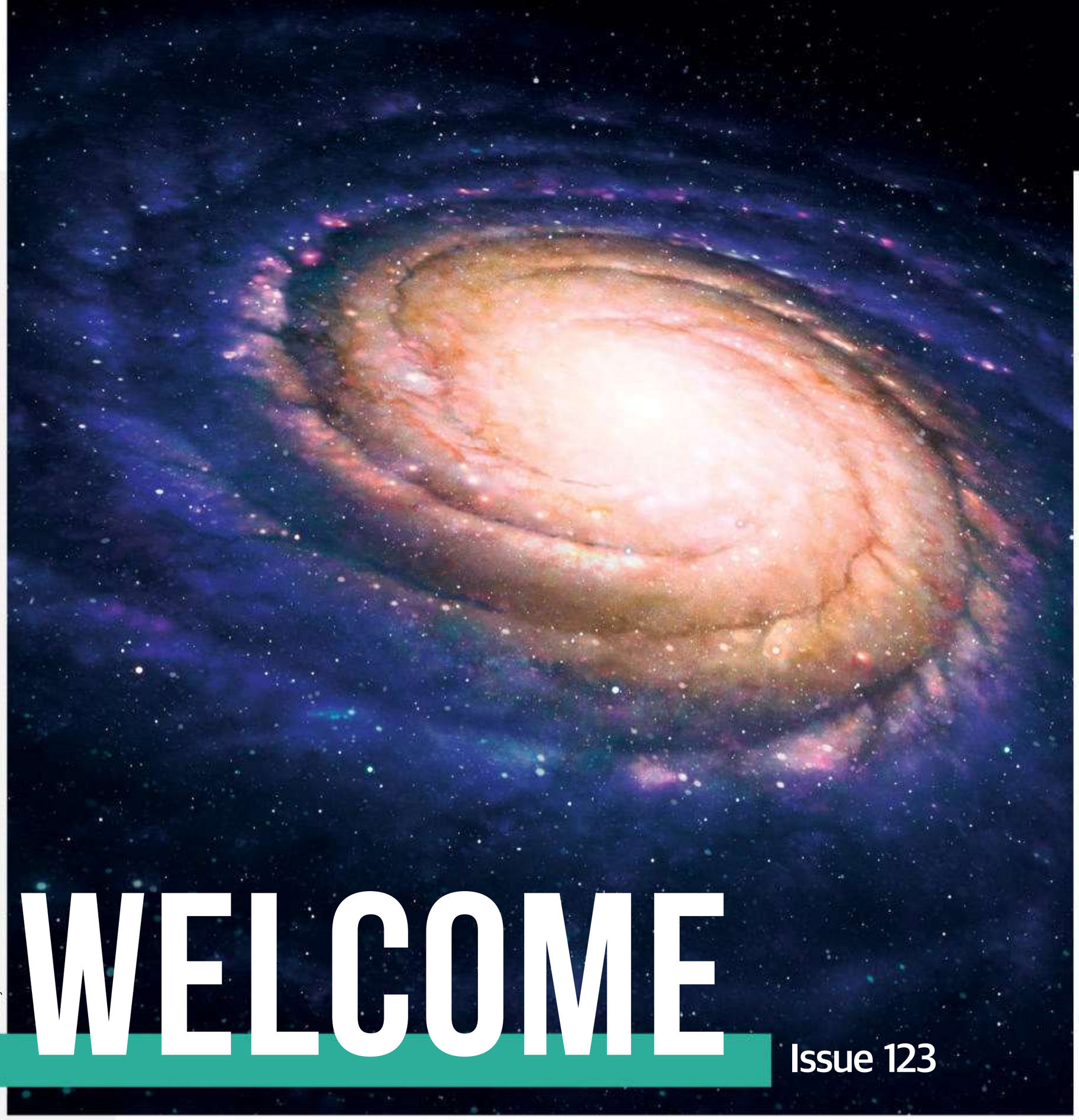

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WELCOME

Issue 123

5 ISSUE HIGHLIGHTS

Greatest craters

From the US and India to Australia and Canada, our travel guide of the very best impacts to visit **16**

Albert Einstein: the biography

A behind-the-scenes look at the life of one of the greatest scientists of all time **32**

Parallel universes

Do other universes exist, and is our universe just one of an infinite number? **44**

Instant expert

What will we do with a captured asteroid? **58**

Beginners guide to binocular astronomy

How to make the most of exploring the night sky **74**

Who's ready for some travelling? As we head into winter, many of us have set our sights on our next holiday destination for when the days get longer. If you're undecided on where to head as 2022 rolls around, never fear – we've got some inspiration in the form of the world's best craters. Whether you're looking to spend a weekend, a day or longer exploring impacts, we've selected the very best sites to visit – and recommended other tourist attractions in the area so you can make the most of your travels. Drop us a line to let us know how you get on.

In between your getaway planning, we've got plenty to keep you entertained this month. From our feature on making the most of observing the night sky with binoculars and exploring the likelihood of parallel universes to our feature on the life of Albert Einstein and the mystery of another potential arm in the Milky Way, there's something for everyone this November.

I'll see you again next issue, where we kick off with a visit to the Red Planet, reveal the most accurate science seen in the movies and show you how you can get started in astrophotography – a hobby that's sure to keep you occupied as we start to roll into 2022!

GEMMA LAVENDER

EDITOR-IN-CHIEF

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INSIDE

16
12 EARTH CRATERS
to visit now

A traveller's guide
to visiting the most
incredible impacts

95 CLAIM YOUR FREE eBOOKS

Black Holes, The Science Collection & Heroes of Space

INSIDE

LAUNCHPAD

06 News from around the universe

FUTURE TECH

24 Mini-magnetospheres
For humans to spread out across the Solar System, we need practical protection from radiation

INTERVIEW

26 Brian Greene
We speak with Brian Greene to discuss how our understanding of the universe around us is always evolving

FOCUS ON

30 Ancient Mars was rocked by eruptions

32 Albert Einstein
Einstein's theories changed the way we think about the universe

FOCUS ON

38 Mystery of empty-sky GRBs cracked

FOCUS ON

42 Are we closer to revealing the secrets of planet formation?

44 Do parallel universes exist?
Science fiction loves a good parallel universe story. But could we be in one?

FOCUS ON

50 2021's giant ozone hole likely due to climate change

52 Missions to the Moon
How spacecraft have helped us pave the way in exploring our neighbour

INSTANT EXPERT

58 What can we do with a captured asteroid?

60 Have scientists found a new arm of the Milky Way?
Astronomers in China have observed a large filament of gas and dust at the outer edge of our galaxy, but what might it be?

FOCUS ON

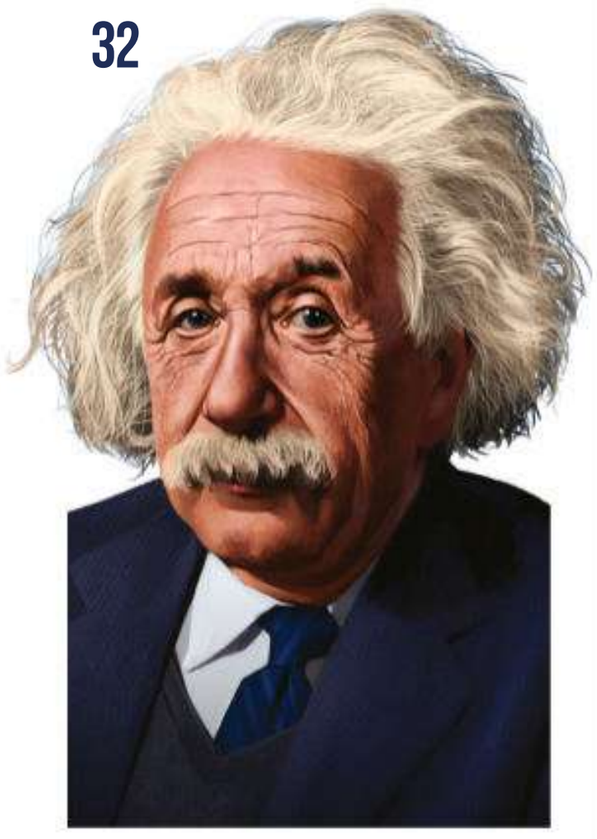
68 United Arab Emirates to launch asteroid mission in 2028

70 Ask Space
Your questions answered by our panel of experts

74 Stargazing with binoculars
Get a new perspective of the jewels of the night sky by stargazing with binoculars

STARGAZER

78 What's in the sky?
82 Month's planets
84 Moon tour
85 Naked eye & binocular targets
86 Deep sky challenge
88 The Northern Hemisphere
90 Astroshots
92 App review
96 In the shops



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LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

29 SEPTEMBER 2021

Worth the wait

Remarkably, it took almost 15 years to acquire this image of Eos Chasma. The image was requested during the first month of the Mars Reconnaissance Orbiter's (MRO) primary science phase in November 2006, but due to numerous competing targets in the Valles Marineris system, the canyon had to patiently wait its turn. And it didn't disappoint. This image shows a huge landslide has occurred, transporting rocks from the canyon's walls down to its floor. The different colours visible to the MRO's High Resolution Imaging Science Experiment (HiRISE) indicate that many different minerals are present.

© NASA/JPL-Caltech/University of Arizona

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

27 SEPTEMBER 2021

All is not quite as it seems

NGC 5728, a captivating spiral galaxy, is harbouring a hidden secret – one out of sight of Hubble's Wide Field Camera 3 (WFC3). This image, captured by Hubble, presents NGC 5728 as a refined barred spiral galaxy, but it's actually an incredibly energetic object known as a Seyfert galaxy, powered by an incredibly active core known as an active galactic nucleus (AGN). A variety of AGNs exist, but only some power Seyfert galaxies. This elegant-looking galaxy is emitting huge amounts of light in parts of the electromagnetic spectrum that Hubble's WFC3 isn't sensitive to.

© ESA/Hubble

LAUNCH PAD

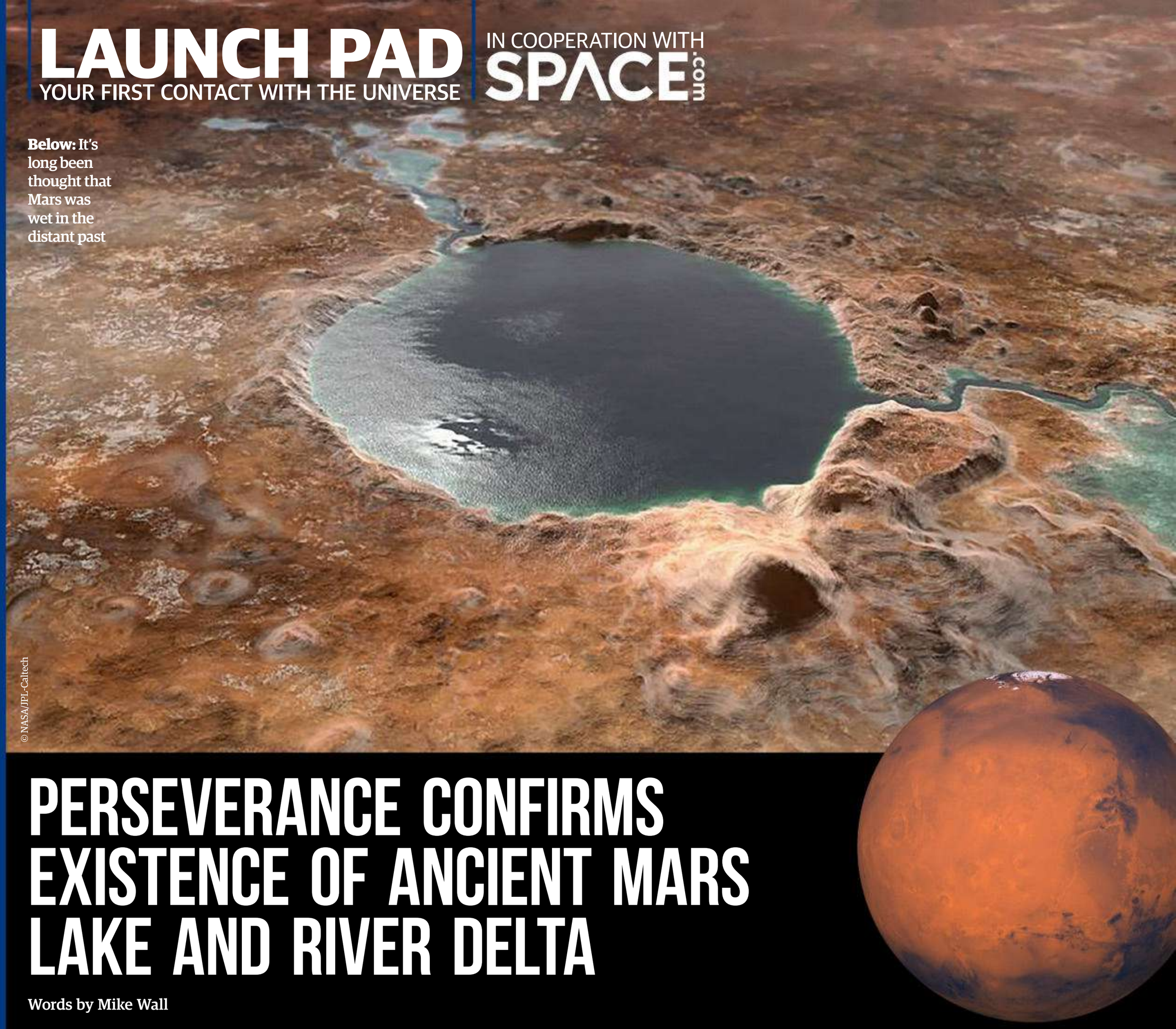
YOUR FIRST CONTACT WITH THE UNIVERSE

20 SEPTEMBER 2021

One for the family album

This impressive image includes almost all of the telescopes at the European Southern Observatory's La Silla Observatory, snaking through the outskirts of Chile's Atacama Desert. At the forefront stands a 3.6-metre (11.8-foot) telescope hosting the High Accuracy Radial velocity Planet Searcher (HARPS) – the leading ground-based exoplanet hunter. La Silla is situated far from light pollution and enjoys some of the clearest night skies in the world. Here, the various telescopes that make up La Silla Observatory can be seen perched along the 2,400-metre saddle-shaped mountain.

© ESO



Below: It's long been thought that Mars was wet in the distant past

© NASA/JPL-Caltech

PERSEVERANCE CONFIRMS EXISTENCE OF ANCIENT MARS LAKE AND RIVER DELTA

Words by Mike Wall

NASA chose the Martian landing site of its life-hunting Perseverance rover wisely. In February 2021, Perseverance touched down on the floor of the 45-kilometre (28-mile) wide Jezero crater, which was picked primarily because previous observations by Mars orbiters suggested that it hosted a large lake and a river delta in the ancient past.

Photos snapped by Perseverance early in its mission – before the car-sized robot even started roving – confirm this interpretation. "Without driving anywhere, the rover was able to solve one of the big unknowns, which was that this crater was once a lake," said Benjamin Weiss, a professor of planetary sciences at the Massachusetts Institute of Technology. "Until we actually landed there and confirmed it was a lake, it was always a question."

Perseverance has two main tasks: hunting for signs of past Mars life and collecting and caching dozens of samples for future return to Earth. The rover also supported and documented the first few sorties of its travelling companion, NASA's Ingenuity Mars helicopter, which is now flying more independently on the Red Planet.

Jezero crater was deemed a good place to do this work based on data gathered by spacecraft such as NASA's Mars Reconnaissance Orbiter. Orbital imagery showed a fan-shaped feature in Jezero that mission team members interpreted as a delta – a place where a river emptied into a lake about 3.7 billion years ago, depositing sediments that could harbour evidence of ancient Martian microbes, if any ever existed.

Scientists analysed early photos that Perseverance snapped of this putative delta from afar with its Mastcam-Z imaging suite and a camera on its rock-zapping SuperCam instrument. These photos captured the edge of the large delta outcrop as well as an isolated butte dubbed 'Kodiak', which the team thinks is an erosional remnant of the same formation. The Kodiak imagery was especially sharp, and in the photos the team saw distinct layers of sediment that could only have been deposited by a river flowing into a lake. The Kodiak observations "point unambiguously towards a deposition of river [sediments] with a delta and a lake," said Nicolas Mangold of the French National Center for Scientific Research and the University of Nantes.

Interestingly, Perseverance's observations show that the ancient Jezero lake was about 100 metres (330 feet) lower than orbital data had suggested. Perseverance will eventually get some up-close looks at the delta formation if all goes according to plan. The team aims to drive the rover, which has travelled 2.62 kilometres (1.62 miles) across Jezero's floor to date, over to the delta outcrop and collect samples deposited during the calm-lake era. Perseverance has already collected two of a planned several dozen samples, which will be hauled to Earth by a joint NASA-European Space Agency campaign, perhaps as early as 2031.

© Blue Origin

Above: An image taken from above the launch

BLUE ORIGIN LAUNCHES WILLIAM SHATNER AND CREW OF THREE TO THE FINAL FRONTIER

Words by Hanneke Weitering

William Shatner has boldly gone where no 90-year-old has ever gone before. The famed *Star Trek* actor and three other private crew members launched into space on 13 October on a Blue Origin New Shepard rocket, marking the second time that Blue Origin has successfully launched a crewed suborbital mission on its vehicle for space tourism. Dubbed NS-18, it was the 18th flight of a New Shepard vehicle overall. "That was unlike anything they described," Shatner was heard saying via a radio link as the capsule parachuted back to Earth.

The reusable New Shepard rocket and capsule lifted off from Blue Origin's Launch Site One, just north of the West Texas town of Van Horn. After an 11-minute flight, during which the crew experienced about four minutes of weightlessness in outer space, the capsule delivered the crew back to Earth with a parachute-assisted landing near Blue Origin's West Texas facilities. Shatner is now the oldest person to have ever flown to space, beating the record set by the 82-year-old aviation pioneer Wally Funk, who flew on Blue Origin's first crewed flight with the company's founder Jeff Bezos on 20 July.

Joining Shatner on the NS-18 mission were three other private crew members, including Audrey Powers, Blue Origin's vice president of mission and flight operations; Glen de Vries, vice chair for life sciences and healthcare at the French software company Dassault Systèmes and Chris Boshuizen, cofounder of the San Francisco-based Earth observation company Planet Labs. Shatner was visibly moved by the experience, wiping tears from his face as he tried to describe it: "What you have given me is the most profound experience I could ever imagine," Shatner told Bezos after the launch.

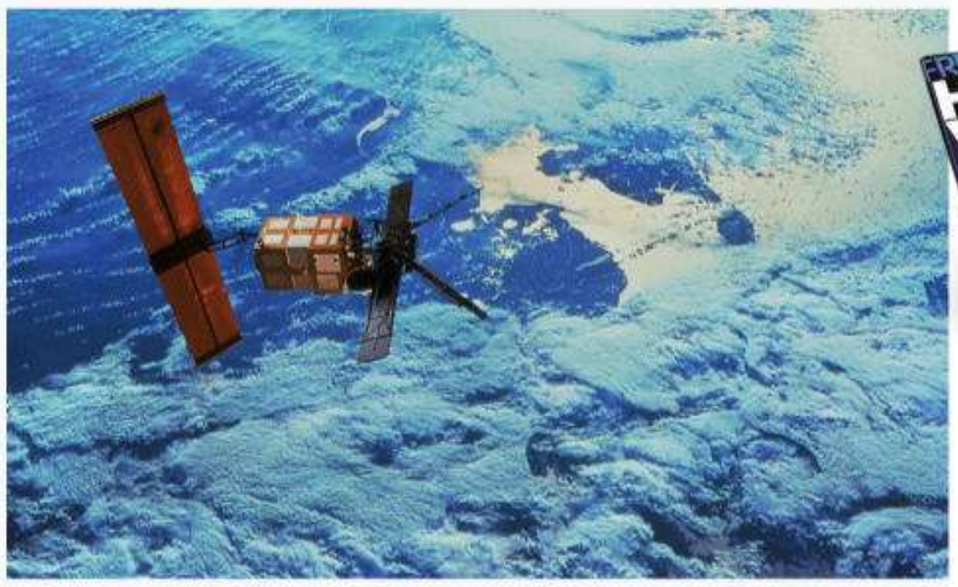
NOBEL PRIZE WINNER SHAPED GROUNDBREAKING EARTH-OBSERVING MISSION

Words by Tereza Pultarova

This year's Nobel Prize in Physics laureate Klaus Hasselmann helped to shape a groundbreaking Earth-observation mission that paved the way for the modern study of our planet's environment. The German oceanographer and climate modeller was awarded the coveted prize for his contribution to the physical modelling of Earth's climate, which has enabled scientists to quantify the climate's natural variability and better predict climate change. Hasselmann won half of the 2021 Nobel Prize for Physics, with the other half shared by scientists Syukuro Manabe and Giorgio Parisi for their own research on disorder and fluctuations in physical systems.

Hasselmann, now 89 and still active at the Max Planck Institute for Meteorology in Germany, was also a member of an expert group that helped the European Space Agency (ESA) create its Earth-observation program and build its first mission dedicated to studying Earth from above in the 1970s. As a member of the space agency's High-Level Earth Observation Advisory Committee, Hasselmann contributed to the development of the European Remote Sensing satellite (ERS-1) and its successor ERS-2.

Below: ERS-1 was launched in 1991, with ERS-2 following in April 1995



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NASA IS READY TO TAKE ON THE WORLD WITH ITS NEW CLIMATE ACTION PLAN

Words by Chelsea Gohd

Climate change and its effects pose such an imminent threat to life as we know it around the world that it is now described as the 'climate crisis'. "NASA has unique assets it must protect – scientific equipment and capabilities that allow us to understand this climate crisis on Earth, as well as explore the universe," said NASA administrator Bill Nelson. "Thankfully, we have the ingenuity and engineering capability to ensure our agency's resources remain resilient from this growing threat. NASA is committed to safeguarding our mission in the decades to come, and through the data we provide to the world, we'll help other agencies make sure they can do the same."

NASA is one of just a few agencies that conducts its own climate research. NASA scientists have been using tools like Earth-monitoring satellites to study Earth's climate and collect valuable data for many years. This has included the study of ice loss, ozone levels, sea-level rise, temperature, precipitation, extreme weather and much more.

NASA's climate change-tackling plan includes five main areas of focus: identifying aspects of climate change that threaten access to space, integrating climate risk analysis and adaptation strategies into NASA's overall plans, integrating climate change resilience planning information into NASA's plans for its centres, developing next-generation climate models and updating climate modelling techniques and collaborating with partners in aviation to reduce carbon dioxide and develop climate solutions.

Above: NASA's new plan of action has five main focus areas

MOON ROCKS BROUGHT TO EARTH BY CHINESE MISSION FILL KEY GAPS IN HISTORY

Words by Meghan Bartels

China's new Moon-rock treasure trove may be a billion years younger than the material the Apollo program brought home decades ago. In December, China's Chang'e 5 spacecraft managed to return 1.73 kilograms of Moon rock from a region called Oceanus Procellarum to scientists on Earth. Since then, scientists with access to the precious material have begun a bevy of experiments to understand the rocks and the secrets of the Solar System that they might hold.

The spacecraft seems to have snagged the perfect sample to fill a critical hole in scientists' knowledge: two tiny pieces have been dated to about 1.97 billion years old, give or take 50 million years. "It's the perfect sample to close a 2-billion-year gap," said Brad Jolliff, a planetary scientist at Washington University in St. Louis in Missouri.

Scientists hoping to untangle the 4.5-billion-year history of the Solar System have combined those time-stamped samples with a technique to identify relative ages called crater dating. "Planetary scientists know that the more craters on a surface, the older it is, and the fewer craters, the younger the surface," said Jolliff. "But to put absolute age dates on that, you have to have samples from those surfaces." The age of the samples is also important because they are a type of rock called basalt, which forms during volcanic eruptions. Scientists previously only had evidence of lava flowing on the Moon up until about 3 billion years ago.

Left: The new rocks point to younger lava flows on the Moon

Right: The signal was mistakenly attributed to a distant galaxy

© CNSA

IN COOPERATION WITH SPACE.com

THE OLDEST GAMMA-RAY BURST EVER DISCOVERED WAS JUST A PIECE OF SPACE JUNK

Words by Tereza Pultarova

A signal that scientists first believed was the discovery of a gamma-ray burst from the oldest known galaxy in the universe was in fact a reflection of sunlight from a spent rocket stage. The disappointing conclusion comes from a team of Polish scientists following a discussion involving several teams about the origin of the serendipitous sighting made by one of the twin Keck telescopes in Hawaii in 2017. Whereas previous contributions to the debate focused on the probability of seeing a satellite compared to an extremely rare gamma-ray burst, the Polish team managed to track down the exact object that caused the flash: a spent Briz-M upper stage from a Russian Proton rocket.

The increasing number of satellites and space debris in orbit interferes with astronomical observations and the exploration of the universe. A recent study estimated that up to 40 per cent of astronomical observations with wide-field telescopes could be ruined after SpaceX deploys all of the currently planned 12,000 satellites of its Starlink constellation.

© NASA/ESA

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To be in with a chance of winning, answer this question:

What is another word for impacts on the surface of the Moon?

A: Mare **B:** Craters **C:** Regolith

Competition ends on 2 December 2021

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EARTH-SHATTERING SIGHTS YOU CAN VISIT IN PERSON OR FROM THE COMFORT OF YOUR HOME

Reported by Daisy Dobrijevic

12 EARTH CRATERS *to visit now*

ISLET OF VILA FRANCA DO CAMPO

SÃO MIGUEL ISLAND, THE AZORES, PORTUGAL

Diameter: 150 metres (490 feet)

Depth: 20 meters (66 feet)

Age: 4,000 years

Earth is perpetually bombarded with space debris, but most of it burns up during entry through the atmosphere. We enjoy this in the form of fleeting meteor showers, though on occasion an object is so big it survives its entry through the atmosphere, leaving its mark. There are 190 confirmed impact structures on Earth, and each one is recorded in the Planetary and Space Science Centre database – a collection of images and publications on impact structures around the world that has been compiled over the last 25 years.

Due to Earth's dynamic climate, processes such as weathering and erosion work to erase any trace of these cosmic visitors from our landscape. Some of the largest impacts to ever occur on Earth are barely visible to us today, at least not in the traditional 'hole in the ground' sense. In South Africa, the Vredefort crater is the world's largest known impact crater. Scientists believe the impact forged a crater between 180 and 300 kilometres (111 and 186 miles) wide, but as the crater has endured over 2 billion years of erosion, the exact size is difficult to determine. Impact craters are a window into the geological past, and scientists study these structures to understand the history of our dynamic Solar System, using this information to predict future impact scenarios.

These structures have impacted Earth in more ways than one, both from a scientific viewpoint and also from a cultural perspective, influencing myths, stories and religious beliefs. Despite our planet erasing them over time, there are a myriad of craters still visible on Earth – some of these, called calderas, are created by powerful volcanic eruptions. You can explore these incredible features yourself, both in real life or from the comfort of your own home via Google Earth.

"SCIENTISTS STUDY CRATERS TO UNDERSTAND THE HISTORY OF OUR DYNAMIC SOLAR SYSTEM"

Things to do at The Site

- Space museum
- Visitor centre
- Crater rim tours
- Gift shop
- 4D theatre

Nearby attractions:

Lowell Observatory, Flagstaff

© Getty

BARRINGER CRATER

LOCATION: ARIZONA, US

Diameter: 1.1 kilometres (0.7 miles) **Depth:** 170 metres (570 feet) **Age:** 50,000 years

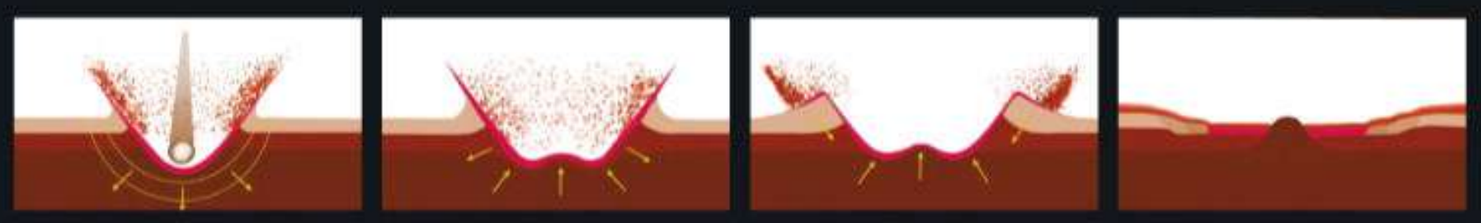
Barringer Crater, also known as Meteor Crater, is privately owned by the Barringer Crater Company – a family-owned enterprise dedicated to the preservation of the crater. The company was founded by Daniel M. Barringer, the first to identify the crater's cosmic origin. Barringer Crater formed relatively recently – geologically speaking, at least – just 50,000 years ago, when a large iron meteor measuring 30 to 50 metres (98 to 164 feet) in diameter crashed into the Colorado Plateau in northern Arizona. The 300,000-tonne meteor was travelling at speeds of up to 41,843 kilometres (26,000 miles) per hour and exploded with the force of two-and-a-half million tonnes of TNT. The impact excavated a whopping 175 million tonnes of rock.

The crater's origin was first identified by mining engineer Daniel M. Barringer, who was convinced the crater was a result of a meteor striking Earth, a view that was not shared by many scientists at the time. Despite the opposition, Barringer spent several years investigating the crater and providing the first proof of its origin, which was eventually vindicated and accepted by the scientific community.

Barringer's interest in the crater was not solely driven by his urge for scientific understanding. Barringer believed that a huge meteorite lay beneath the crater and that it could be mined for its valuable metal content. He spent the rest of his life attempting to mine the crater, but his efforts were in vain, as the majority of the meteorite would have been destroyed on impact. Today the Barringer Crater Company aims to preserve the crater and ensure appropriate access by the public via the Meteor Crater and Barringer Space Museum visitor centre.

MAKING A BIG IMPRESSION

How a classic crater formation is created by large impacts



SMASHING IN

Complex craters are formed by large impacts, tending to be wider, but shallower in depth.

CRATER WALLS

The force causes the walls to collapse downwards, adding debris to the interior.

CENTRAL PEAK

Craters also have a hump in the middle, where material has rebounded from the impact.

FINAL DIAMETER

On different planets, gravity has a significant effect on the type of crater formed.

© Getty; FreeVectorMaps.com

© Alamy

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LONAR CRATER

LOCATION: MAHARASHTRA, INDIA

Diameter: 1.8 kilometres (1.1 miles) **Depth:** 137 metres (449 feet) **Age:** 55,000 years

Nestled inside the Deccan Plateau lies Lonar Crater, a large meteorite crater that has baffled scientists since it was identified in 1823 by British officer J. E. Alexander. The crater is located within a huge plain of basaltic rock left over from volcanic eruptions in the region 65 million years ago. It is the only known crater to have formed in basalt. As such, the crater was originally thought to be a volcanic crater. Nowadays it is known that the crater formed around 55,000 years ago as a result of a meteor impact.

The unique ecosystem is a haven for local flora and fauna; the low crater hills are covered with trees, and are home to several species of wildlife, including peafowl, chinkara and gazelles. Migratory birds can also be spotted flocking to the lake during the winter months. The crater site is also of great cultural significance, featuring in Hindu mythology. It's considered to be the place where Vishnu slayed the demon Lavanasura. It's believed the crater was the demon's lair, and the lake is a result of its spilled blood. The cultural importance is echoed by the numerous temples – built around the 12th century – found around the crater's edge. While most of the temples now lay in ruin, one temple dedicated to the local goddess Kamalaja Devi is still used for active worship.

Scientists flock to Lonar Lake not just to study the unique basalt-based crater, but also the lake itself, which is both saline and alkaline. In June 2020, Lonar Lake surprised scientists and locals alike when it turned a rosy pink. The striking colour change was most likely caused by a large population of salt-loving 'Haloarchaea' (or 'halophilic archaea') microbes, which produce a distinct pink pigment. This elaborate transformation was short-lived, however, as by July 2020 the lake had reverted to its original form.

© NASA

©Getty

TSWAING CRATER

LOCATION: GAUTENG, SOUTH AFRICA

Diameter:
1.1 kilometres (0.7 miles)
Depth: 100 metres (330 feet)
Age: 220,000 years

Approximately 40 kilometres (25 miles) northwest of Pretoria, within the area of the City of Tshwane, is the Tswaing meteorite crater – originally known as Pretoria Saltpan, or Zoutpan. Tswaing is one of the best preserved craters in the world, and sediment deposits from the crater floor contain 220,000 years of climate records. Visitors to the site can enjoy the 7.2-kilometre (4.4-mile) Tswaing Crater Trail, as well as a museum display, and enjoy the diverse wildlife that resides in the conservation area.

Things to do at the site

Guided crater tours

Wildlife tours

Temple visit

Nearby attractions:

Aurangabad is home to many attractions, including Aurangabad Caves, Bibi Ka Maqbara and the ancient water mill Panchakki

TAP HERE TO PLAY

©Getty

Things to do at the site

Crater walk
Nature observation
Hiking

Nearby attractions:
Scenic air flight from Halls Creek, a small town on the eastern edge of Kimberley

© NSAA

WOLFE CREEK CRATER

LOCATION: WOLFE CREEK METEORITE CRATER NATIONAL PARK, AUSTRALIA

Diameter: 875 metres (2,871 feet) **Depth:** 60 metres (196 feet) **Age:** 150,000 years

Positioned on the edge of the Great Sandy Desert in northern Western Australia, Wolfe Creek Crater - known to Aboriginal Australians as Kandimalal - is a truly extraordinary sight. Wolfe Creek Crater was thought to have formed 300,000 years ago, though recent studies have estimated the age of the crater to be a lot younger, around 150,000 years.

A prominent feature of the landscape, Wolfe Creek Crater is the second-largest crater in the world from which fragments of a meteorite have been collected. Scientists estimate that the crater-forming meteor - predicted to have been 15 metres (50 feet) in diameter and weighing approximately 14,000 tonnes - was probably travelling at eye-watering speeds of 17 kilometres (10 miles) per second before slamming into the Australian desert.

The crater was only discovered by Europeans in 1947 during an aerial survey of the region, but Wolfe Creek has long been known to Aboriginal people, known as Janyil in Djaru and as Karntimarlarl in Walmajarri. There are many stories associated with the crater among the indigenous communities of Australia. One story involves two giant ancestral snakes, who formed the nearby Sturt and Wolfe Creeks when they made their way across the desert. The crater is where one of the mythological snakes emerged from the ground.

The crater lies 145 kilometres (90 miles) from the nearest town, Halls Creek. The isolation has helped preserve the crater and surrounding area, and Wolfe Creek Crater was given Class A Reserve status in 1979, adding further protection to this astonishing landmark. People are encouraged to visit the crater during the dry season - May to October - as access to the site is via a gravel road, and is not appropriate for unconventional vehicles. There is a 400-metre (1,312-foot) return walk to the crater rim which involves a steep, rocky climb, and climbing down into the crater is forbidden due to loose rocks making it dangerous. Wolfe Creek Crater is home to some interesting wildlife, including the vocal Major Mitchell's cockatoo harvesting seeds from plants on the crater floor and brown ring-tailed dragon lizards on the hunt for insects.

TENOUMER CRATER

LOCATION: MAURITANIA

Diameter:
1.9 kilometres (1.2 miles)
Depth: 110 metres (360 feet)
Age: 21,400 years

Deep in the Sahara Desert is a near-perfect circular crater. The origins of the crater had long been debated among geologists, with some arguing that it was the remnants of a volcano. But when scientists examined the crater in more detail, they noticed that the crater's hardened 'lava' was in fact rock that had been melted during the impact. Tenoumer is one of the trickiest crater sites to visit due to its remote location. From the Mauritanian capital Nouakchott it's an 11-hour drive to the nearest town of Zouérat, which is still some 200 kilometres (124 miles) away as the crow flies.

© NASA

GOSSE BLUFF (TNORALA)

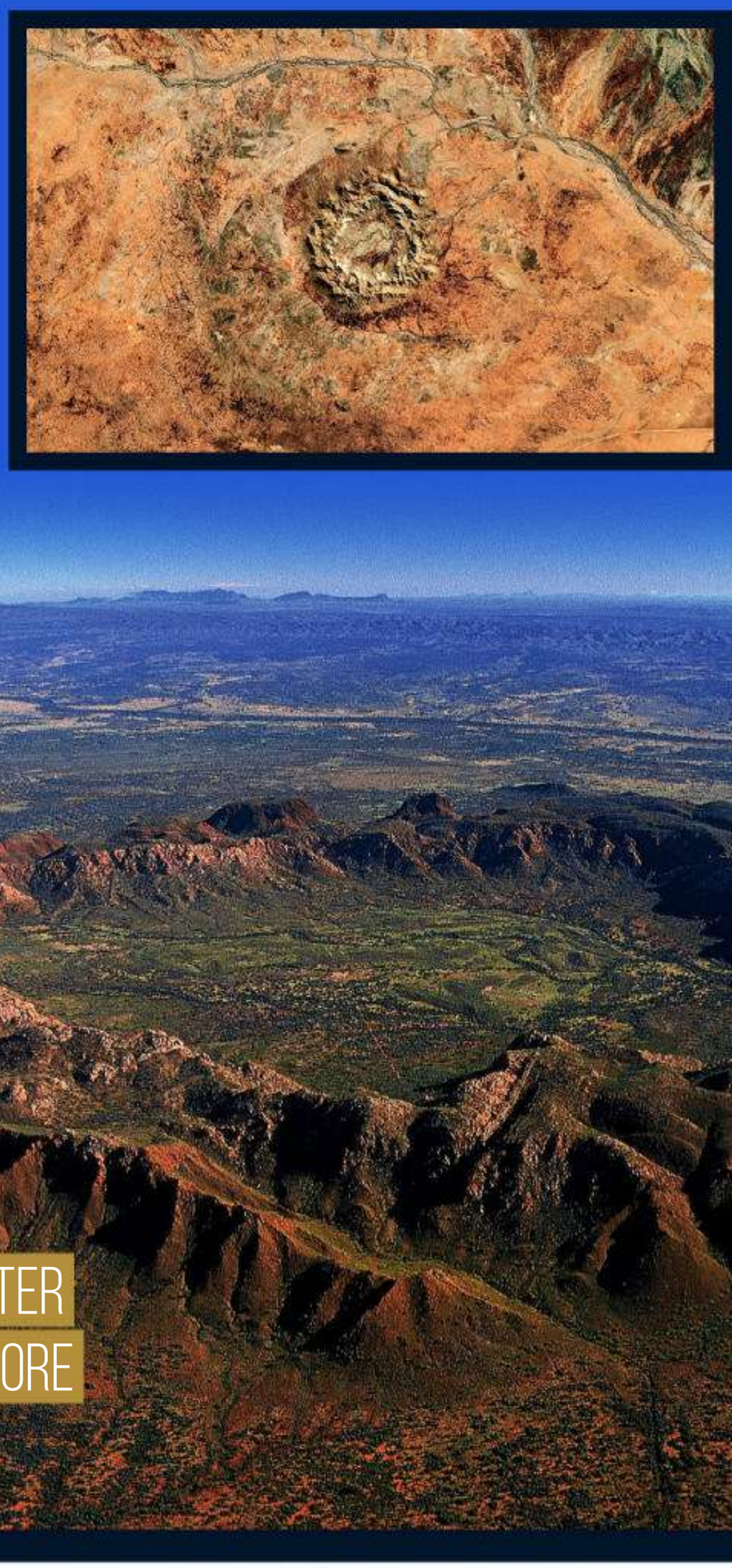
LOCATION: NORTHERN TERRITORY, AUSTRALIA

Diameter: 22 kilometres (13.6 miles), now 4.5 kilometres (2.7 miles)
Depth: Five kilometres (three miles) **Age:** 142 million years

Australia is home to more impact craters than any other part of the world. Gosse Bluff is of great cultural and scientific importance. Those wishing to access the crater must respect its importance to the Western Arrernte Aboriginal people and obey signs stating where access is not allowed.

Scientists believe that a meteor travelling at speeds of up to 40 kilometres (25 miles) per second slammed into Earth 142 million years ago, creating a giant crater nearly 22 kilometres (13.6 miles) wide. While the original crater has been eroded over the years, the core of the crater, a central ring of hills almost 4.5 kilometres (2.7 miles) in diameter, is still visible to this day. The remnant crater was given the name Gosse Bluff by the explorer Ernest Giles in 1872 – he named the crater after Henry Gosse, a fellow of the Royal Society.

The Tnorala Conservation Reserve is a registered sacred site. As such, traditional owners welcome visitors to experience Tnorala, but ask those visiting to exhibit respect for the area – and walking on the crater rim is forbidden. The Aboriginal interpretations of the crater are similar to those of scientists in that they too have celestial origins. The Aboriginal people believe Tnorala was formed when a group of women danced across the sky as the Milky Way. During the dance, a mother put down her baby to rest in a carrier. The carrier fell over and crashed to Earth, where it became the circular rock walls of Tnorala. The reserve lies approximately 175 kilometres (108 miles) from Alice Springs, and access with four-wheel drive is recommended.



"WHILE THE ORIGINAL CRATER HAS BEEN ERODED, THE CORE IS STILL VISIBLE"

© Alamy

ROTER KAMM CRATER

LOCATION: TSAU KHAEB NATIONAL PARK, SOUTHWEST NAMIBIA

Diameter: 2.5 kilometres (1.6 miles)
Depth: 130 metres (426 feet) **Age:** 4.8 million years

Amid the rusty-red dunes of the Namib Desert is a crater that looks like it'd be right at home on Mars. Roter Kamm crater is found in Tsau Khaeb National Park – also known as the Sperrgebiet – a mining area in southwest Namibia. Remarkably, scientists believe that the meteorite that formed this crater 4.8 million years ago was only the size of a large vehicle when it collided with Earth. The impact gave rise to a crater rim 40 to 90 metres (131 to 295 feet) above the surrounding plains, while the crater floor is blanketed in sand deposits at least 100 metres (330 feet) thick.

© NASA

IMPACTS THROUGH TIME

3,240 YEARS AGO
KAALI CRATER FIELD

21,400 YEARS AGO
TENOUMER CRATER

50,000 YEARS AGO
BARRINGER CRATER

55,000 YEARS AGO
LONAR CRATER

150,000 YEARS AGO
WOLFE CREEK CRATER

220,000 YEARS AGO
TSWAING CRATER

1.4 MILLION YEARS AGO
PINGUALUIT CRATER

4.8 MILLION YEARS AGO
ROTER KAMM CRATER

15 MILLION YEARS AGO
NÖRDLINGER RIES

142 MILLION YEARS AGO
GOSSE BLUFF (TNORALA)

Things to do at the Site

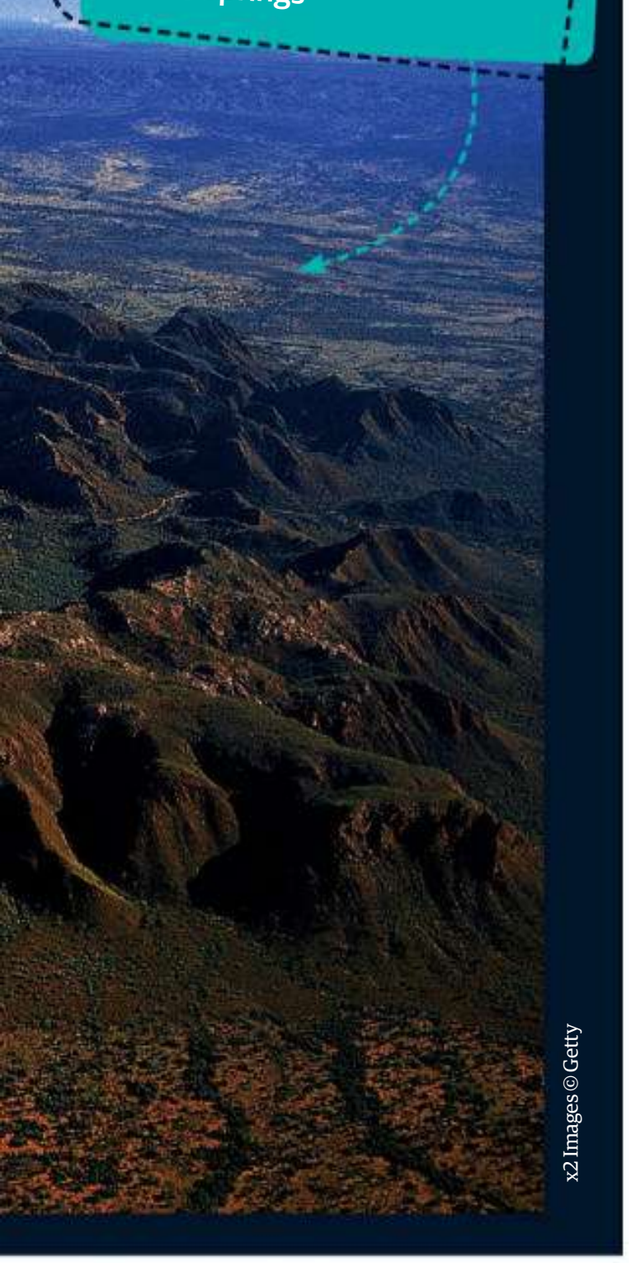
View the interior of the crater via a short walk to a lookout point and a longer loop walk which provides a higher vantage point

Picnic areas

Nearby attractions:

Ayers Rock is around 450 kilometres (280 miles) away from Alice Springs

The Museum of Central Australia is located in the Araluen Cultural Precinct in Alice Springs



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PINGUALUIT CRATER

PINGUALUIT NATIONAL PARK, QUEBEC, CANADA

Diameter: 3.4 kilometres (2.1 miles)
Depth: 400 metres (1,300 feet) **Age:** 1.4 million years

Pingualuit National Park is situated in the heart of the Ungava Peninsula and is home to the impressive Pingualuit Crater. Under the arctic sky, the crater is filled with pristine rainwater, cut off from inflows from other lakes. This unique underwater environment provides scientists with a window into the geological past. Sediments of the lake were untouched during the Pleistocene Ice Age – a time period that began about 2.6 million years ago and lasted until about 11,700 years ago. While other sediments in surrounding water bodies do not extend further back than the last ice age, those found in the Pingualuit Crater have preserved a far longer record.

The crater was first observed from the air in 1943, when the crew of a United States Air Force plane flew over the impact site, though expeditions didn't commence until the 1950s due to the remoteness of the crater. However, there is evidence that the crater site has long been known to the local Nunamiuts – nomadic Inuits who lived off the resources of the interior Ungava lands. There are traces of rock shelters and stones arranged in a circular pattern – evidence of where old tents would have been erected. The traces suggest the Nunamiuts once set up camps on the ridges of the Pingualuit Crater while scouting for promising hunting grounds.

Things to do at the Site

Wildlife observation

Hiking

Nearby attractions:

Kite-skiing on nearby Lake Manarsulik as well as dog sled rides, fishing trips, cross-country skiing and alpine snowshoe treks.

NÖRDLINGER RIES

LOCATION: WESTERN BAVARIA, GERMANY

Diameter: 24 kilometres (15 miles) **Depth:** 100 metres (330 feet) **Age:** 15 million years

Remarkably, the Ries crater contains a city – Nördlingen – within the structure's inner ring, and the full impact of the crater can only be seen when viewed from the air. While the inner ring is highlighted by the town walls, the rest of the crater has been eroded away and isn't immediately visible. The crater's existence probably eluded the medieval Europeans, who unknowingly matched their town walls to the inner crater ring approximately one kilometre (0.6 miles) in diameter – likely the same dimensions as the crater-forming meteorite.

The true origins of the crater also eluded residents of Nördlingen for over 100 years. It was long believed the Ries structure was an extinct volcanic crater, but when geologists Eugene Shoemaker and Edward Chao visited the town in the 1960s, they found overwhelming evidence that Ries was an impact crater.

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KAALI CRATER FIELD

LOCATION: KAALI, ESTONIA

Diameter: 12 to 110 metres (39 to 360 feet) **Depth:** 1 to 22 metres (3.3 to 72 feet) **Age:** 3,250 years old

Why visit one crater when you can visit nine? Located on Estonia's largest island, Saaremaa, 18 kilometres (11 miles) from the island's capital Kuressaare, is the Kaali crater field, consisting of one large crater and eight smaller ones.

The island is thought to have already been inhabited at the time of the meteorite impact, but the crater field's age is still a matter of debate; estimates range from 2,420 to 7,600 years old, though recent estimates suggest it's around 3,250 years old. Nevertheless, the event would have been quite the spectacle when the meteor broke apart into fragments when it was just five to ten kilometres (three to six miles) above the ground. The pieces then smashed into the Estonian island, creating some of Earth's youngest giant craters.

Despite the impact occurring during a time of possible human habitation, there's no evidence that the encounter significantly affected human occupancy on Saaremaa. However, domestic animal bones have been found at the site, and a large stone wall was built around Kaali Lake around the beginning of the Common Era, suggesting that the area was once used as a sacrificial site. The scientific and cultural significance of the Kaali crater field can be explored in greater detail at the Kaali Meteoritics and Limestone Museum. Here you can also view various fossils on display and learn about other discoveries made on the island of Saaremaa. A guide service is available in Estonian, English, Finnish and Russian, and there is also a gift shop.

Things to do at the site

Kaali Meteoritics and Limestone Museum

Kaali Tavern

Nearby attractions:

Thule Koda museum in Kuressaare, Saaremaa

Kuressaare beach

Nihatu Hiking Trail

© Getty

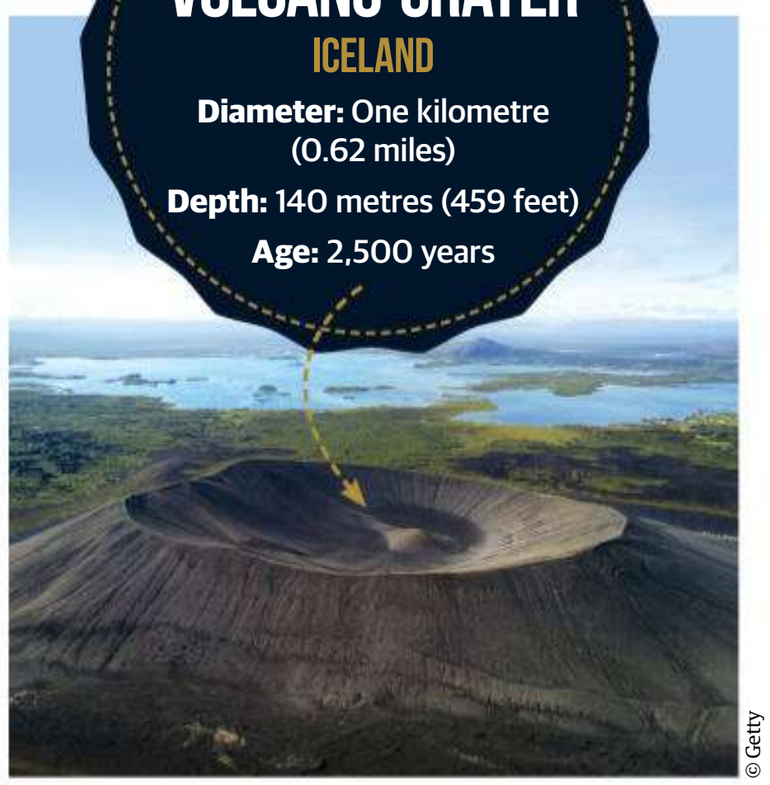
HVERFJALL VOLCANO CRATER

ICELAND

Diameter: One kilometre (0.62 miles)

Depth: 140 metres (459 feet)

Age: 2,500 years



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GOOGLE EARTH

Unfortunately, not every Earth crater site is easily accessible in real life. However, all of these craters (and more) can be found and explored on Google Earth. Here you can view the craters from different angles, and in some cases even see what it looks like at the crater floor from photographs submitted by those who have been fortunate enough to visit – Lonar Crater is one such example.

Google Earth is easily accessible via a web browser with the web address **earth.google.com**. We would recommend viewing on a desktop rather than a mobile. You can find craters by typing their names into the Google Earth search bar, or if you would like to take a tour of the ten craters listed in this article, you can follow this link: **tinyurl.com/u5fxsx9u**. Here you'll find a list of the craters we've explored, and you can visit each one by clicking on its name, or by pressing 'present' for the full tour.

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SPACECRAFT MAGNETOSPHERES

For humans to spread out across the Solar System, we need practical protection from solar and cosmic radiation on long voyages

Whenever the USS Enterprise encounters hazards - be they physical or electromagnetic - captains Kirk and Picard call for the shields to go up; these force fields form an elliptical shell around the ship, keeping the crew safe. While we're a long way off *Star Trek* levels of protection, we really do need something to minimise crew radiation exposure on flights beyond Earth orbit. Current Mars plans propose creating a small solar storm shelter surrounded by water or layers of hydrogen-rich plastics like polyethylene, and SpaceX's Elon Musk has spoken about his Interplanetary Transport System coasting along with the propellant tanks pointed towards the Sun. But Oxford University's Dr Ruth Bamford has a better idea: she suggests a mini-magnetosphere.

Though space appears empty, it's actually teaming with high-energy particles, and the dominant factor within the Solar System is the solar wind. This is a diffuse, neutral plasma of mostly hydrogen streaming out from the Sun. Plasma is often described as the fourth state of matter - after solid, liquid and gas. If material is heated further, the electrons break free of the atomic nuclei and the matter becomes a cloud of ions - stripped, positive nuclei - and free electrons. Plasma is conductive to electricity and is much easier to form under low pressures. We encounter high-temperature plasmas in ordinary flames, but relatively cold low-pressure plasmas in fluorescent lights.

Solar plasma travels at very high speeds, so if its ions encounter a spacecraft they can pass through the hull and damage the DNA of prospective space travellers, potentially causing radiation sickness or death. Though in principle we could simply protect crew with thick walls of material, such spacecraft would end up impractically massive. But we have another model: the giant spaceship keeping us all safe right now, Earth. The environs of Earth, stretching to many times the planet's diameter, are protected by Earth's magnetic field, which is known as the magnetosphere.

Bamford and a team of scientists at the Rutherford Appleton Laboratory (RAL) have been studying how a spacecraft could create its own mini-magnetosphere, protecting the ship without needing an impractical amount of power or mass. It's not just a case of creating a magnetic field around a spaceship, but using a magnetic field to trap its own region of stationary benign plasma around the ship. This is partly how the Earth's protection works. Earth's magnetic field has gradually captured plasma from the solar wind, and it's this cushion that opposes the incoming wind.

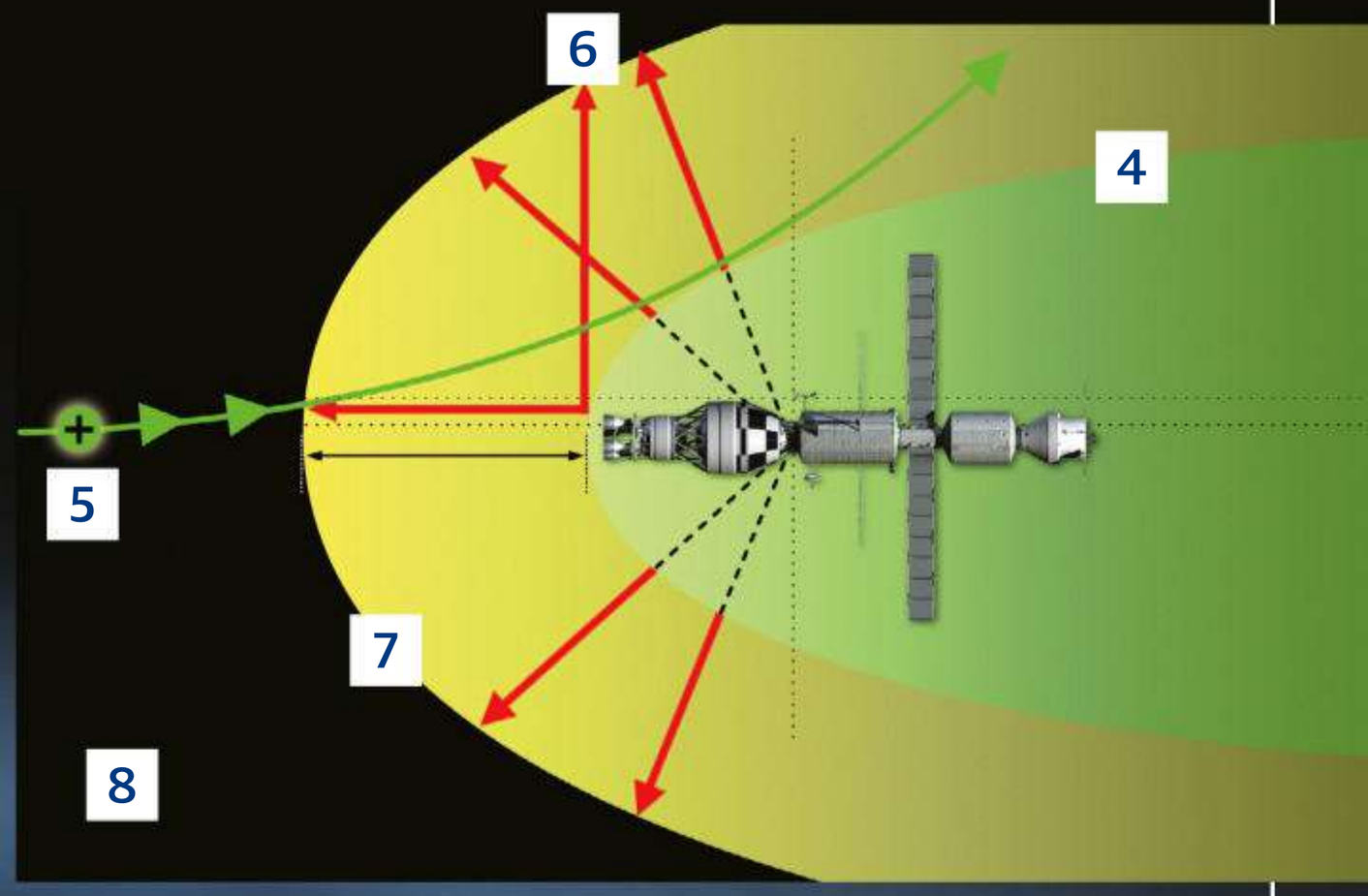
The insights to potentially creating such shields have come from RAL's work on nuclear fusion. In that case, researchers are trying to contain high-temperature neutral plasma inside a magnetic field using a doughnut-shaped vacuum vessel called a tokamak. This is the inverse of what we need to do in space, and is actually more challenging because the plasma is of a greater temperature than within the Sun. Indeed, one proposed concept for a shielded ship is a doughnut-shaped crew compartment

© Adrian Mann

surrounded by superconducting magnets, or an inverted tokamak.

To create such a shield in practice, a spacecraft would establish a magnetic field and then fill it with self-generated plasma. The plasma supports the field, and the interaction with the solar wind helps to sustain the effect, minimising the power required. The plasmas involved are still of incredibly low density, and it should be a rapid process to establish the shield.

The same principle could ultimately be used to protect planetary bases as well. The Moon, Mars and Venus all lack an Earth-like magnetosphere, so habitats on the lunar or Martian surfaces, or floating in the Venusian atmosphere, would also benefit from the mini-magnetosphere shielding effect.



1 DEEP-SPACE MODULE
The main power and propulsion systems are sited in the deep-space module at the rear. This might include a nuclear reactor for longer trips.

2 ARTIFICIAL GRAVITY
In the interests of crew health, the ship could have a rotating ring habitat to provide artificial gravity. This is at the centre of the magnetosphere.

3 CREW TRANSPORT
This modular spacecraft, developed from Bamford's research, features a crew transport capsule for travel to and from the ship.

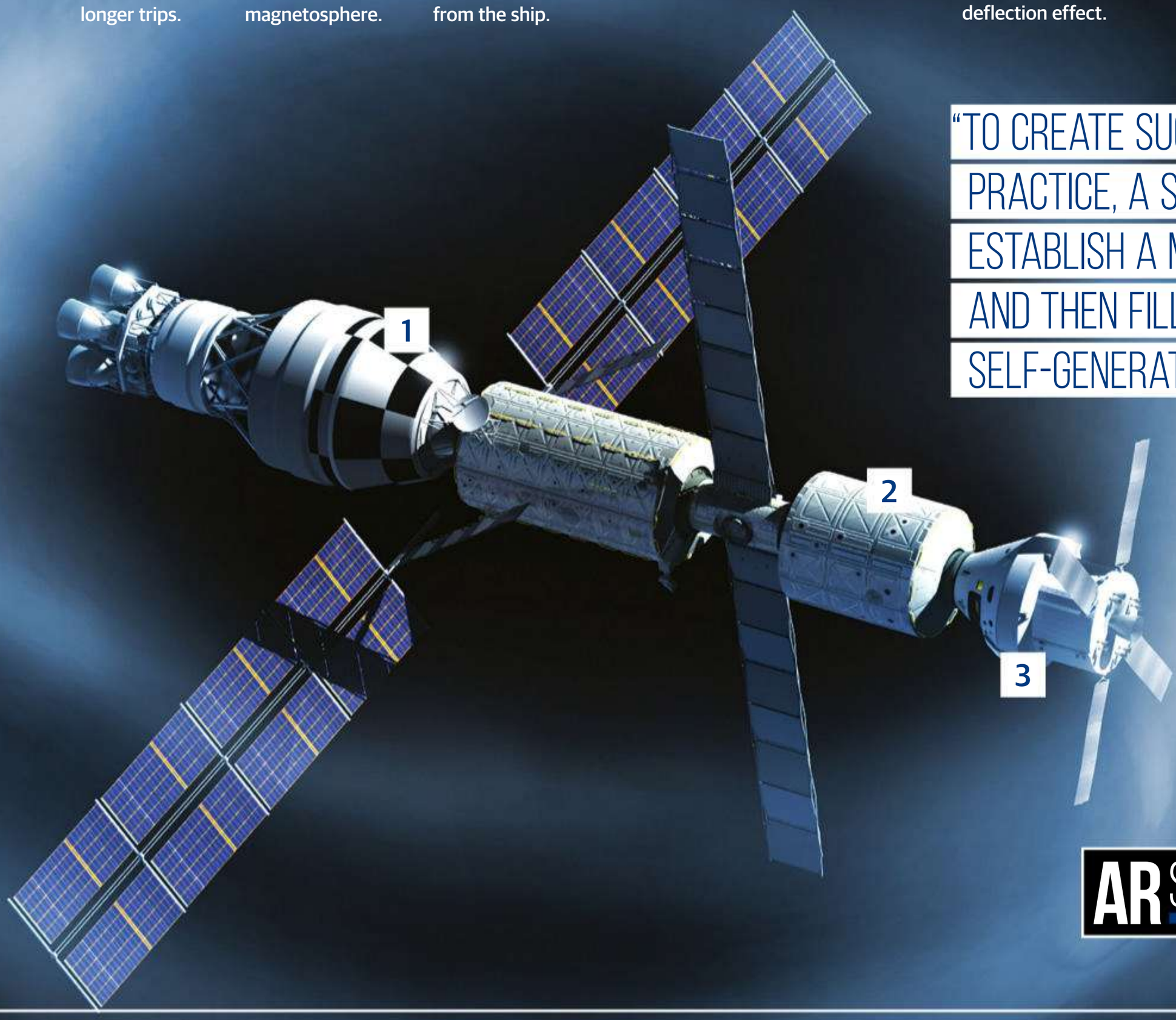
4 THE SAFE ZONE
Sustained by the self-generated plasma trapped within the magnetic field, the ship and crew are protected within.

5 POSITIVE IONS
Nuclei in the solar plasma are stripped of their electrons, becoming positively charged.

6 DEFLECTED IONS
The combination of the magnetic field and interacting plasmas creates electrical currents, creating electric fields that contribute to the deflection effect.

7 BOW SHOCK
As the solar wind smashes into the shield, it pushes it into a bow-wave shape that then trails out behind the ship like a comet.

8 INTERPLANETARY SPACE
The ISS and satellites are protected within Earth's magnetosphere, but the solar wind dominates interplanetary space.



"TO CREATE SUCH A SHIELD IN PRACTICE, A SPACECRAFT WOULD ESTABLISH A MAGNETIC FIELD AND THEN FILL IT WITH SELF-GENERATED PLASMA"

AR SCAN HERE

INTERVIEW

BIO

Brian Greene

Greene, a theoretical physicist at Columbia University, has been working for decades to advance our understanding of the universe and how it works. That work includes significant discoveries in the field of string theory, one of the most promising 'theory of everything' candidates. He also makes it a priority to spread the word of such discoveries to the masses. Greene cofounded and chairs the World Science Festival and has also written a number of best-selling, critically acclaimed popular-science books.

© Alamy

BRIAN GREENE

“IT’S A WONDERFUL, DYNAMIC PROCESS OF HUMAN DISCOVERY”

All About Space speaks with Brian Greene to discuss how our understanding of the universe around us is always evolving

Interviewed by Mike Wall

It feels like we’re really coming into a golden age of black hole astronomy. We’ve got the Event Horizon Telescope (EHT), which gave us our first direct image of a black hole, and we’re seeing a lot of black hole mergers thanks to the Laser Interferometer Gravitational-Wave Observatory (LIGO). Do you feel we’re finally getting a better handle on these objects? If so, what could that tell us about the universe?

There was a time, ten years ago, when you could still make an argument that black holes aren’t real – they’re just a figment of mathematics. But with LIGO, with the collision of two black holes giving that ripple in the fabric of space, and with the EHT, black holes have come into their own. For someone like me who works on cutting-edge theoretical ideas, we’re struggling now to merge black holes and quantum mechanics to get a full understanding. Black holes are the prime theoretical laboratory for pushing our ideas to the limit. When we can fully understand black holes and quantum mechanics, our understanding of the universe is going to jump to a new level.

Are you optimistic that that’s going to happen relatively soon? Do you think there are breakthroughs on the horizon?

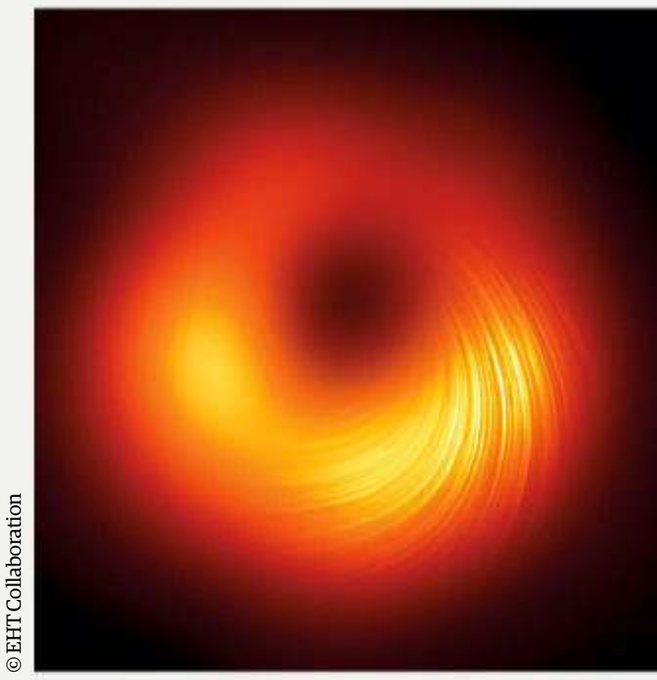
Yeah. There are many of us – those people who work on string theory and quantum gravity. Focusing upon black holes is really the predominant occupation at the moment. There’s so much exciting work that’s happening that I would suspect that even a year or two from now, our understanding today will look relatively primitive to the new ideas that will be developed.

People often throw up their hands after they read a study that says ‘we’ve made a big breakthrough’ and then they see another study that says, ‘actually, no’. A lot of people don’t know how science works, that it’s a process that builds upon things step by step and everything is always in flux. Is that something that you try to get across to people when you’re teaching them about science?

It is. Because if you view science as just a body of facts that are static, then you’re missing the drama of the discovery, where people put forward ideas, others react to the ideas, people test and observe and come back. It’s a wonderful, dynamic process of human discovery. And when you see science in that light, it brings it to life in a way that a textbook of facts could never.

I find talking to people – and to kids especially – they often don’t even view scientists as real people. They’re seen as caricatures, the wild-haired

Right: Following the release of the first image of a black hole in 2019, astronomers captured a new polarised view of the same black hole



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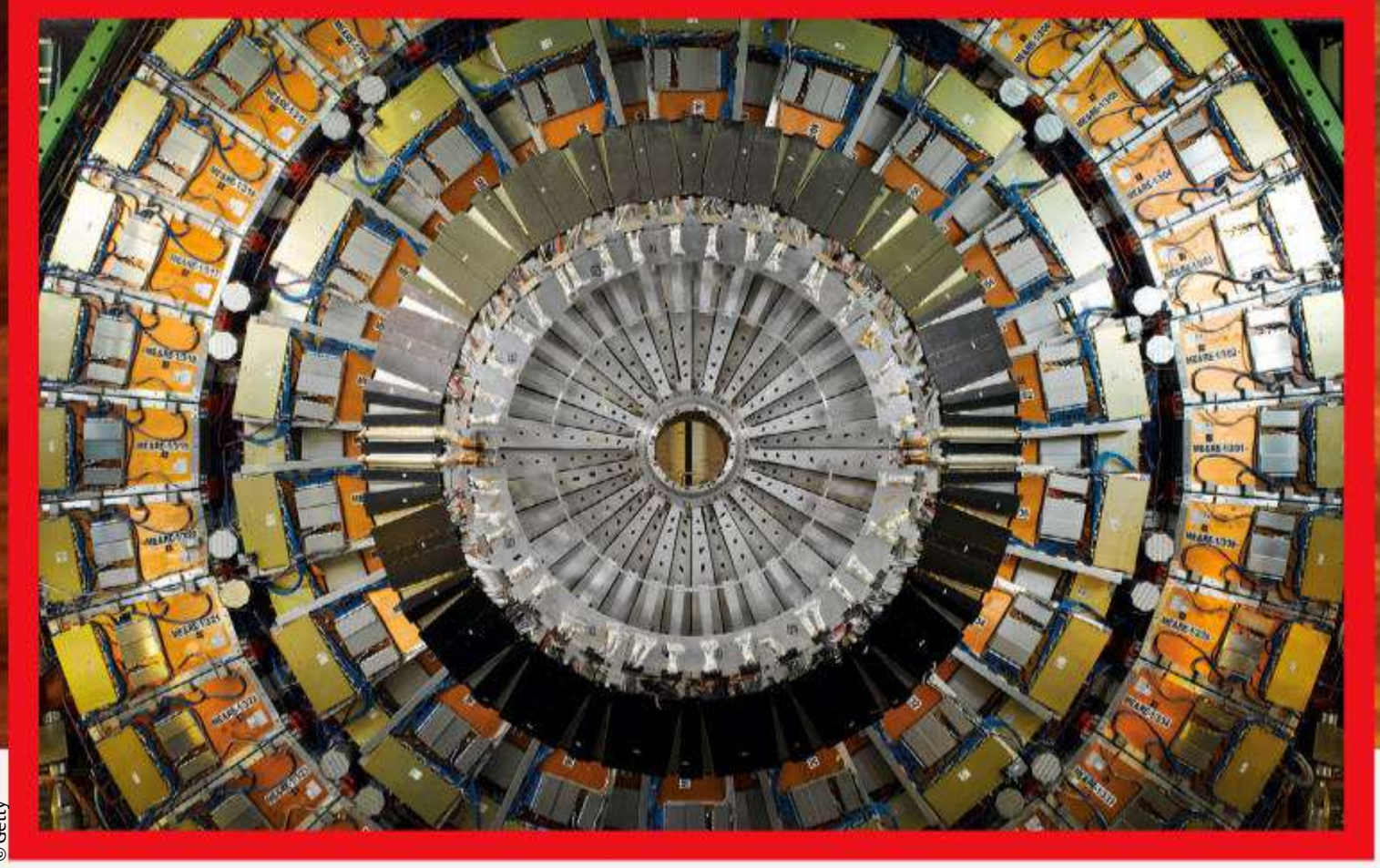
Below: The Large Hadron Collider located in Geneva, Switzerland, is the world's largest and highest energy particle accelerator



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guys in the movies. I think it's really important to emphasise to kids that scientists are just people like them or like their mum or dad, and that's something that most people don't internalise.

It's an important lesson. And there have been attempts – television shows, you know, *The Big Bang Theory* perhaps being the most prominent of them. But again, in *The Big Bang Theory* the scientists were somewhat caricatures, right? It was good that it was mainstream, but still there's a tendency to see scientists as this weird collection of people. In any large group, there are weird folks. But the vast majority of people are just like everybody else and just focus their attention on a certain class of questions.

Scientists are trying to come up with a theory of everything, to find one that stands the test of time. Do you still feel like that's going to be string theory? Has what we've learned over the past five or ten years changed any of your thinking on the biggest questions?

Just to be clear, although I'm known for working on string theory and bringing string theory to general populations, I have never, ever said I believe in string theory. I have always said I have confidence that this is an interesting idea worthy of our attention that may ultimately be the final theory, but we just don't know yet.

My assessment is pretty stable; it's pretty much the same. In the last few years there have been great theoretical breakthroughs in string theory. There's been less contact with experiments than I would have hoped. I'd hoped that the Large Hadron Collider would reveal some of the hints of string theory. That hasn't happened. But that may well mean that the theory needs a bigger, better, more powerful machine to probe it, and that's not unexpected.

I'd say that developments are happening at a fast and furious pace on the theoretical side in the hope that we'll have some connection to experiments or observations in the not-too-distant future. But that's difficult to predict.

Are there any experiments or projects in particular whose results you're most looking forward to seeing in this regard? What could help us make progress?

Right now, it's likely that if we do get any insight from observations into string theory, it could come from, say, verifying gravitational-wave observatories that might be able to probe the outskirts of a black hole with unprecedented

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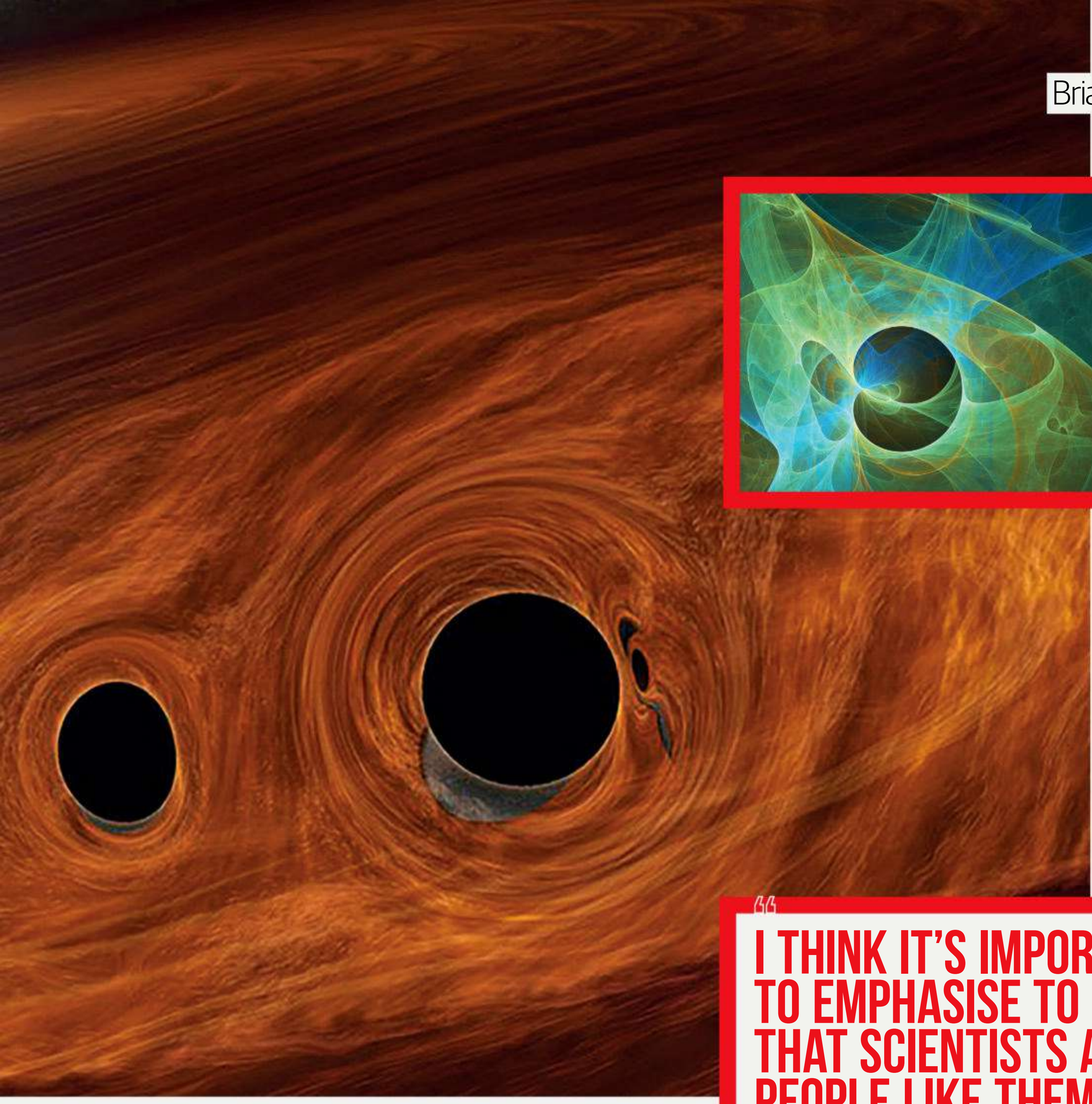

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Above: String theory is one of the most promising candidates to explain all known phenomena in the cosmos

Left: A supermassive black hole surrounded by a cloud of gas and two smaller black holes

> I THINK IT'S IMPORTANT TO EMPHASISE TO KIDS THAT SCIENTISTS ARE JUST PEOPLE LIKE THEM

precision. It's conceivable that in these kinds of experiments we might get a hint. But if you're asking me in my heart of hearts, I think it's probably going to be the case that in our lifetime we're not going to get that observation or experimental insight. It may be the next generation or the generation beyond that.

That's a little disappointing from an individual perspective because we all want to know; we all want to get the answers. But science is a process, and we've only been at this – trying to marry all the forces of nature and everything into one cohesive whole – for about a century, right?

Even less at some level. There was work a century ago, but I'd say [the last] 50 years is when the real work has happened. And we're trying to push our understanding so far beyond the reach of today's experiments that it's not surprising that it may take a few generations to get there. We're trying to answer some of the deepest questions that have ever been asked.

How did the universe begin? How do the fundamental forces integrate with one another? What are the fundamental ingredients? These are questions that, in one way or another, we've been asking for a thousand, or a couple thousand, years. If it takes another handful of decades before we get real insight, that's just how it is.

Do you have confidence that our brains are actually capable of plumbing these depths? We're basically apes that evolved to survive on the savanna on a timescale of around 7 million years. Are we capable of actually getting to the bottom of these mysteries, which may be much deeper than we can possibly comprehend?

I'm fundamentally an optimistic person, so I've always imagined that the answer to that question is yes. But you look around this planet and there are intelligent creatures like dogs and cats, who I suspect don't understand Einstein's general theory of relativity. Maybe I'm wrong; perhaps the dogs and cats are all laughing at us right now. Maybe they've got the final answer.

But putting that to the side, it could be that our brains are simply too limited to access the final answer, even though it's staring us in the face right now. But you go forward, you push as hard as you can. We haven't hit any insurmountable obstacles yet, and so we maintain our optimism and try to find the final answer.

ANCIENT MARS WAS ROCKED BY VIOLENT, CLIMATE-CHANGING VOLCANIC ERUPTIONS

Supereruptions regularly tore up the surface of the Red Planet billions of years ago

Reported by Tereza Pultarova

"EACH ONE OF THESE ERUPTIONS WOULD HAVE HAD A SIGNIFICANT CLIMATE IMPACT" PATRICK WHELLEY

Main: Mars hosts the largest volcano in the Solar System: Olympus Mons

A team of geologists has found evidence that large craters visible in satellite images of northern Mars' Arabia Terra region were not created by asteroids, as some had originally believed, but by massive volcanic eruptions that blasted billions of tonnes of gas and molten rock up into the atmosphere. Better known as calderas, these craters are essentially the remnants of once-powerful explosive supervolcanoes, and they have more irregular shapes than their asteroid-created counterparts. But since those powerful eruptions are believed to have taken place some 4 billion years ago, finding conclusive evidence about their nature required forensic methods.

The scientists looked for traces of volcanic ash, modelling how it would disperse after such eruptions and where it would deposit. Then they looked at high-resolution images taken by NASA's Mars Reconnaissance Orbiter to see whether the patterns matched their expectations.

"At that point we said, 'these are minerals that are associated with altered volcanic ash, which has already been documented, so now we're going to look at how the minerals are distributed to see if they follow the pattern we would expect to see from supereruptions,'" said Alexandra Matiella Novak, a volcanologist at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland. The new research built on Novak's previous studies of volcanic ash deposits in other regions of Mars.

What the researchers found in the images matched the models. The ash spread downwind, eastward from the seven calderas revealed in the Mars Reconnaissance Orbiter images. The deposited ash was traceable thousands of miles away from the craters, with the layer thinning out farther away from the source. "We're actually seeing what was predicted, and that was the most exciting moment for me," said Jacob Richardson, a geologist at NASA's Goddard Space Flight Center in Greenbelt, Maryland, who was part of the research.

The supervolcanoes, likely active during a period of 500 million years some 4 billion years ago, spewed massive amounts of water vapour, carbon dioxide and sulphur dioxide into the atmosphere of Mars, throwing the planet's climate off balance for decades. "Each one of these eruptions would have had a significant climate impact – maybe the released gas made the atmosphere thicker, or blocked the Sun and made the atmosphere colder," said Patrick Whelley, a geologist at Goddard. "Modellers of the Martian climate will have some work to do to try to understand the impact of the volcanoes."

The last supervolcano eruption on Earth took place 76,000 years ago in Sumatra, Indonesia. But terrestrial calderas, dozens of miles wide, are spread around the globe in known tectonically active regions, where the majority of smaller but still active volcanoes also reside today.

The strange thing about the Martian Arabia Terra, however, is the fact that it doesn't show traces of smaller volcanoes. The scientists speculate that calderas on Earth may have been eroded over billions of years or moved around the globe with the shifting continents. These types of explosive volcanoes could also exist in regions of Jupiter's moon Io, or could have been clustered on Venus.

Earlier this year, scientists from the Planetary Science Institute in Tucson, Arizona, found evidence that Mars might still be volcanically active today. However, most of the Red Planet's volcanic activity occurred in the era of the supervolcanoes some 4 billion years ago. Mars' 21.9-kilometre (13.6-mile) high Olympus Mons, the biggest volcano in the Solar System, is believed to have last erupted about 25 million years ago.

© Getty

ALBERT EINSTEIN

THE LIFE OF A BRILLIANT PHYSICIST

EINSTEIN'S THEORIES CHANGED THE WAY WE THINK ABOUT THE UNIVERSE

Reported by Adam Mann and David Crookes

Einstein remains the rock star of science – the go-to icon when people discuss intelligence. You certainly don't have to be an Einstein to understand the man's impact or get a handle on how eager people have been to discover what made him tick. And it says it all that a pathologist removed his brain just hours after death, eager to discover if there was something extra special within the genius' grey matter. Whether Einstein approved of such an act is still up for debate. It's said that he had wanted his brain to be used for research, but there is no firm evidence. If anything, though, it's just one more thing to discuss and pick at, given we all know just how much scientists love to dissect and analyse Einstein's many theories. That scientists are still proving him right all of these years on says it all, and if he was alive today, you'd bet he'd be flashing his infamous grin.

His work keeps him at the forefront of our minds. As well as being famous for his theory of relativity – a pillar of modern physics that describes the dynamics of light and extremely massive entities – the physicist's work in quantum mechanics, which focuses on the subatomic realm, has also had a huge impact. What is all the more surprising is that his parents felt he was slow to learn. He didn't utter his first word until he was four years old. Born in Ulm, in the German state of Württemberg, on 14 March 1879, Einstein had a disrupted childhood. His family moved to Munich six weeks after his birth, and when he was five years old he began attending Petersschule, a Catholic elementary school. Contrary to popular belief, Einstein was a good student. "Yesterday Albert received his grades. He was again number one, and his report card was brilliant," his mother once wrote to her sister. But when he later switched to the Luitpold grammar school, young Einstein was not able to cope with the school's authoritarian attitude, and his teacher once said of him: "Never will he get anywhere."

"THE PHYSICIST'S WORK IN QUANTUM MECHANICS, WHICH FOCUSES ON THE SUBATOMIC REALM, HAS ALSO HAD A HUGE IMPACT"

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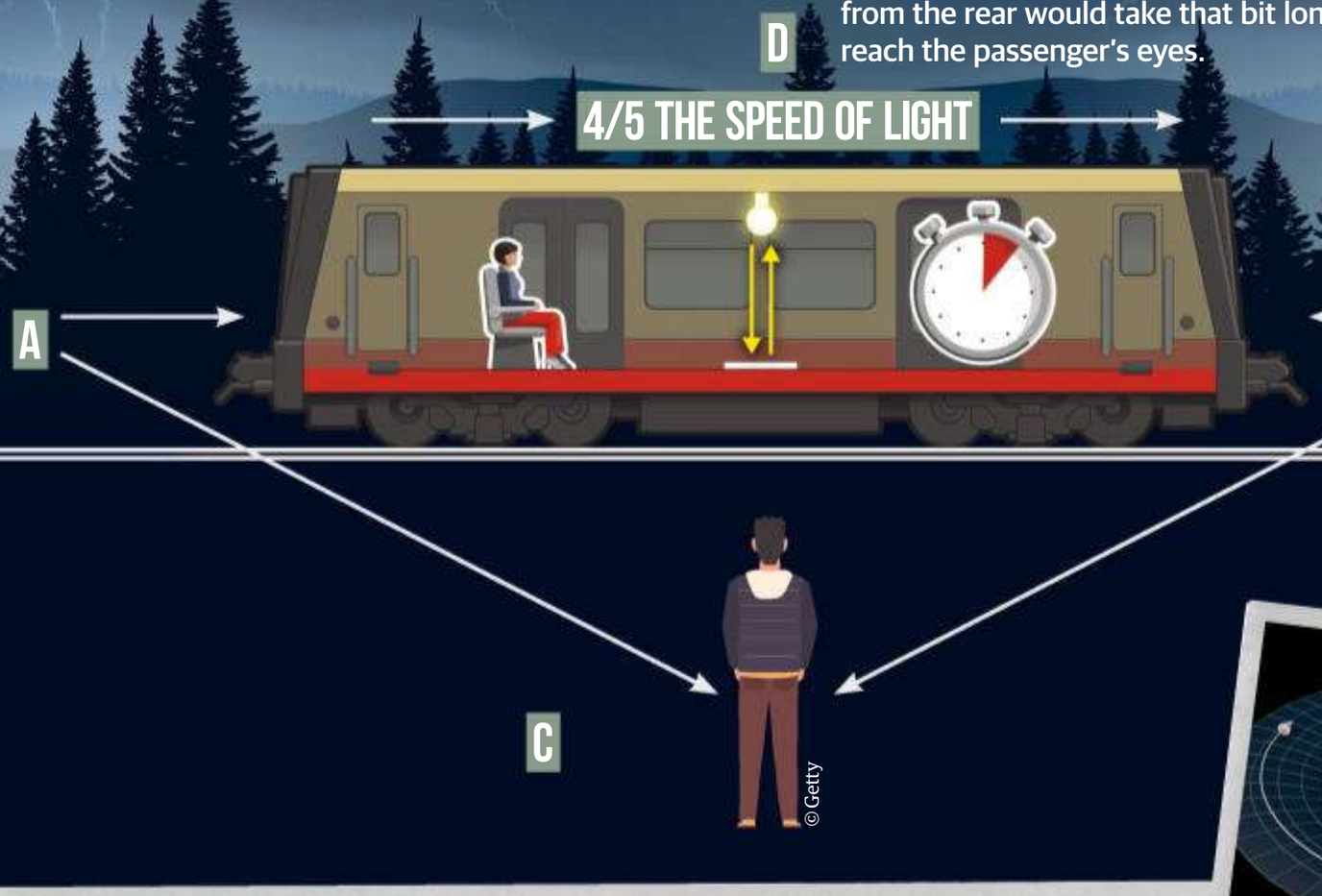
BLUFFER'S GUIDE TO EINSTEIN'S THEORIES OF GENERAL AND SPECIAL RELATIVITY

WHEN DID EINSTEIN MAKE A BREAKTHROUGH?

In 1905 Einstein published his theory of special relativity. It explained the relationship between space and time, based on the concept that light travels at a constant speed of 299,792 kilometres (186,000 miles) per second and that the laws of physics are the same for everyone. He figured that it would be possible for two people to witness two events occurring simultaneously yet see them at different times. Motion would affect how each person observed the events.

AND WHAT DOES THAT MEAN?

Einstein gave an example involving two people – one standing on a railway platform and another sitting at the exact midpoint on board a train travelling at a constant speed. As the train passes the platform and the midpoint aligns with the person there, lightning strikes both the front and back ends of the train. It could be assumed that both people believed the strikes took place simultaneously. This is indeed what happened. But the person sitting on the train will observe that the lightning struck the front of the train first. The movement of the train means the light from the rear would take that bit longer to reach the passenger's eyes.



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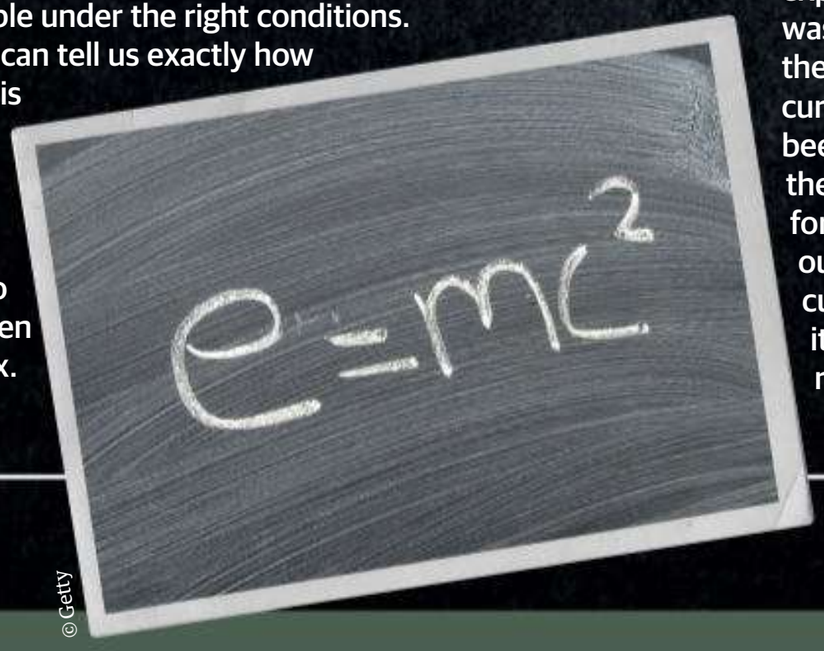
SOUNDS SIMPLE ENOUGH. IS THAT IT?

There's a bit more to it. The theory also uses the speed of light to define the relationship between energy and matter. Most people are familiar with one of the most famous equations ever created: $E=mc^2$. It means energy is equal to mass times the speed of light squared – or that energy and mass are interchangeable under the right conditions. The equation can tell us exactly how much energy is obtained from converting mass. But it led Einstein to something even more complex.



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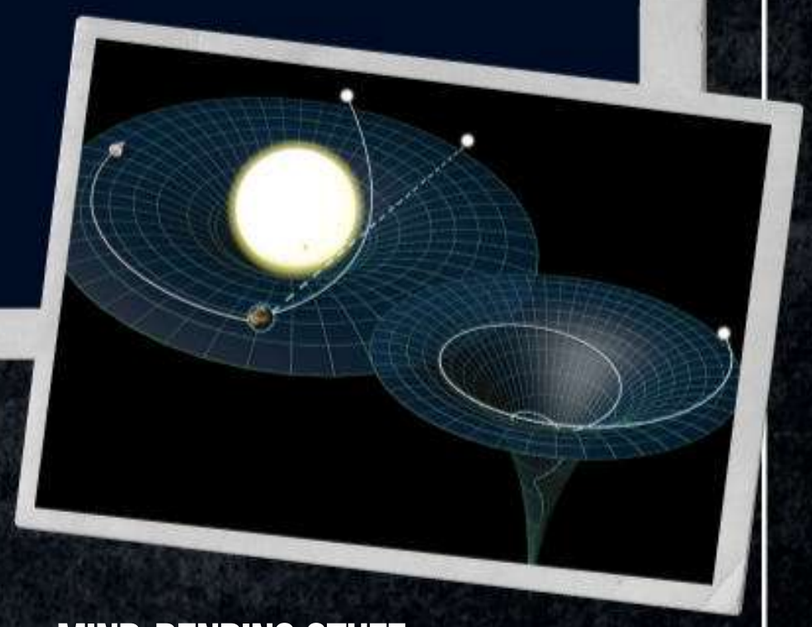
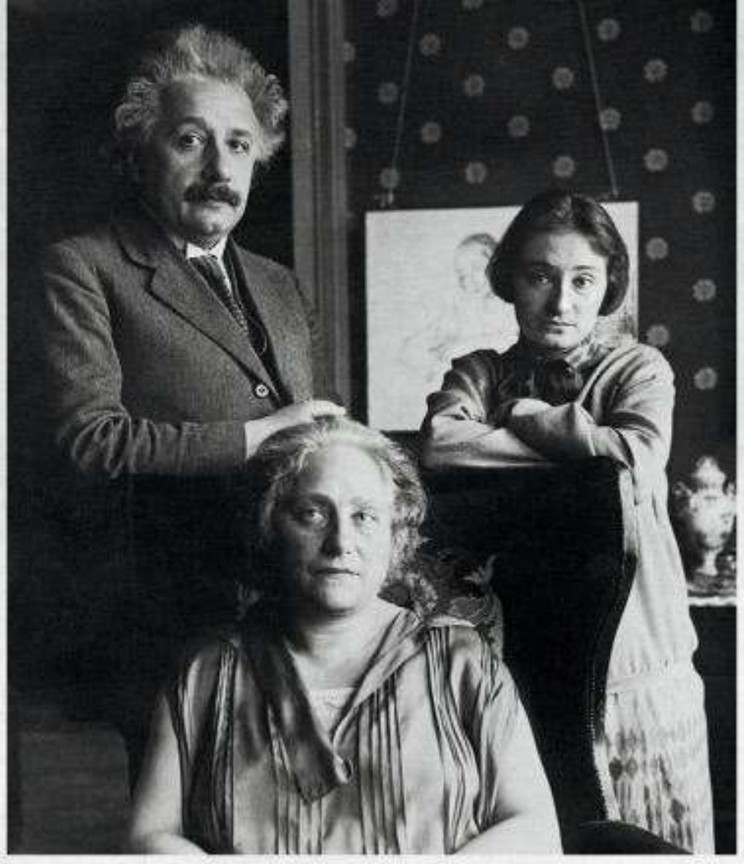
WOULD THAT BE GENERAL RELATIVITY?

Yes. After years of work, Einstein published his theory of general relativity, which enabled it to work when taking the effects of gravity into account. What we experience as gravity, he posed, was not an invisible force, but the result of massive objects curving space-time itself. It had been thought, for instance, that the Earth moved because of the force of gravity, but Einstein said our planet's orbit was because curved space-time was forcing it along the shortest possible route around the Sun.



MIND-BENDING STUFF

What's more, this also led to the theory of black holes, where the curvature of space-time around extremely dense objects is infinite. This forms a hole in the fabric of space-time. General relativity also showed that time can be dilated due to a difference in the strength of gravity – climb Everest and your clock will tick faster than that of a friend who decided to stay at the bottom. The theory also showed that the path of light can be bent by gravity so that the position of stars are false when viewed from Earth. It also led to the development of the Big Bang theory.



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In 1897, at age 17, Einstein entered the Swiss Federal Polytechnic School in Zurich to be trained as a teacher in physics and mathematics. A few years later, he gained his diploma and acquired Swiss citizenship, but he was unable to find a teaching post, so he accepted a position as a technical assistant in the Swiss patent office.

In 1903, Einstein married Mileva Marić, his longtime love and former student. A year prior, they had a child out of wedlock, who was discovered by scholars only in the 1980s when private letters revealed her existence. The daughter, called Lieserl in the letters, may have been mentally challenged, and either died young or was adopted when she was a year old. Einstein had two other children with Marić: Hans Albert and Eduard. They were born in 1904 and 1910 respectively.

Around this time, Einstein was excelling academically, obtaining his PhD in physics in 1905. This year could be referred to as his annus mirabilis – 'marvellous year' in Latin – and that's because he published four groundbreaking papers of significant importance in physics. They would turn science well and truly on its head. The first incorporated the newly conceived idea that light could come in discrete particles called photons. This theory describes the photoelectric effect, the concept that underpins modern solar power. The second explained Brownian motion – in which a small bit of dust is seen to move randomly on the surface of water – by pointing out that water is made up of tiny, vibrating molecules that kick the dust back and forth.

The final two outlined his theory of special relativity, which showed how observers moving at different speeds would disagree about many measurements, but would agree about the speed of light, which is a constant. These papers also introduced the equation $E=mc^2$, showing the equivalence between mass and energy. That finding is perhaps the most widely known aspect of Einstein's work – in this famous equation, E stands for energy, m represents mass and c is the constant speed of light.

In 1915, Einstein published four more papers, outlining his theory of general relativity. They updated Isaac Newton's laws of gravity by explaining that the force of gravity arose from warps in the fabric of space-time caused by massive objects. The theory was given a major validating boost in 1919, when British astronomer Arthur Eddington observed stars at the edge of the Sun during a solar eclipse and was able to show that their light was bent by the Sun's gravitational well, causing shifts in their perceived positions.

Einstein divorced Marić in 1919, and he soon married his cousin Elsa Löwenthal, with whom

Above: Einstein with his second wife Elsa and her daughter Margot

Below: The famous physicist giving a speech in August 1930

"HE UPDATED ISAAC NEWTON'S LAWS BY EXPLAINING THAT THE FORCE OF GRAVITY AROSE FROM WARPS IN THE FABRIC OF SPACE-TIME CAUSED BY MASSIVE OBJECTS"

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EINSTEIN TIMELINE

1879

Albert Einstein was born in Ulm, Germany, to Hermann Einstein and Pauline Koch.

1884

He had private lessons and was given a compass by his father.

1891

Developed a thirst for scientific knowledge with help from medical student Max Talmud.

1892

Didn't attend his Bar Mitzvah.

1894

His parents moved to Milan, Italy, for work, but he remained in Germany for a further year.

1895

He failed the entry exam for the Federal Institute of Technology (ETH) in Zurich.

1896

Renounced German citizenship.

1900

Having attended ETH, he graduated with a diploma as a mathematics teacher.

1901

Einstein became a Swiss citizen, but struggled to find work.

1902

Einstein was employed at the Swiss Patent Office in Bern.

1905

Einstein published groundbreaking papers, including his theory of special relativity, equivalence of mass and energy, Brownian motion of particles and atomic theory.

1909

He became an associate professor at ETH, teaching theoretical physics.

1911

Predicted the bending of starlight at eclipses and became the youngest physicist to attend the world's first Solvay Conference in Brussels.

FIVE THINGS EINSTEIN'S THEORIES CORRECTLY PREDICTED

GRAVITATIONAL WAVES

Einstein's general theory of relativity predicted ripples in the fabric of space-time called gravitational waves. Set off by violent cosmic cataclysms, they were finally observed in 2016 – a little over 100 years after they were proposed – when the Laser Interferometer Gravitational-Wave Observatory picked up two neutron stars colliding. Gravitational waves have been notoriously difficult to prove because their distortion of space-time is miniscule by the time they reach us.

© NASA

LIGHT'S SPEED LIMIT

Einstein predicted that light always travels at the same speed – 299,792 kilometres (186,000 miles) per second – and claimed it didn't matter how much energy is contained in a particle of light because there will not be any difference in speed. Some scientists predicted this may not be the case, and that higher energy photons travelled slower than those of lower energy. But an observation by the Fermi Gamma-ray Space Telescope found Einstein was correct.

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BLACK HOLES

The theory of relativity predicted that space-time could be deformed by a compact mass to form a black hole. It also said the gravitational pull of a black hole would bend light waves, as well as release them from the other side. This was proven in July 2021 when Stanford University astrophysicist Dan Wilkins detected light from behind a black hole for the first time. He and his colleagues observed X-rays coming from the far side.

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GRAVITATIONAL LENSING

Einstein predicted that each ray of light that we detect on Earth has been deflected as it travels through space. Massive celestial objects are able to bend the passing light by a small degree, and that would need to be taken into account during observations. The first gravitational lens was discovered in 1979, when the Twin Quasar was observed. Its appearance was distorted by the gravity of a galaxy closer to Earth in the same line of sight.

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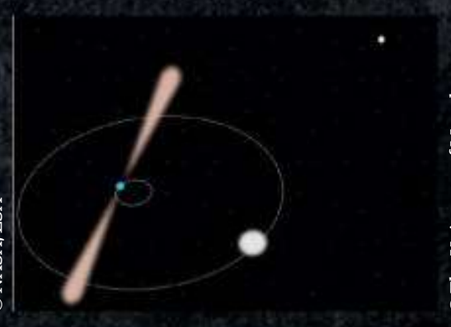
THE UNIVERSALITY OF FREE FALL

The theory of general relativity says two objects dropped in a gravitational field will fall with the same acceleration regardless of mass or composition. This was confirmed by astronomers at the University of Manchester in 2020 by measuring the movement of a white dwarf and a pulsar orbiting a second white dwarf. Both the pulsar and the white dwarf orbited exactly the same, falling "with the same acceleration in the gravitational field of a third".



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PHILOSOPHICAL LEANINGS

Einstein said he owed an intellectual debt to the philosopher David Hume in a letter which emerged as recently as 2019. Although Hume's ethics have recently been called into question for writing 'racist epithets', Einstein avidly studied *A Treatise of Human Nature*, published in 1739, shortly before he discovered the theory of relativity. "It is very possible that without these philosophical studies, I can not say that the solution would have come," he wrote.

Hume believed that time didn't exist separately from the movement of objects, and he also believed scientific concepts should not only be based on reason, but evidence and experience. Einstein said philosophical thinking was the difference "between a mere artisan or specialist and real seeker after truth". It's understood that he was introduced to Hume's work when he was in Switzerland.

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"OTHER RESEARCHERS WERE CREATING A REVOLUTION BY REFORMULATING THE RULES OF THE SMALLEST KNOWN ENTITIES IN EXISTENCE"

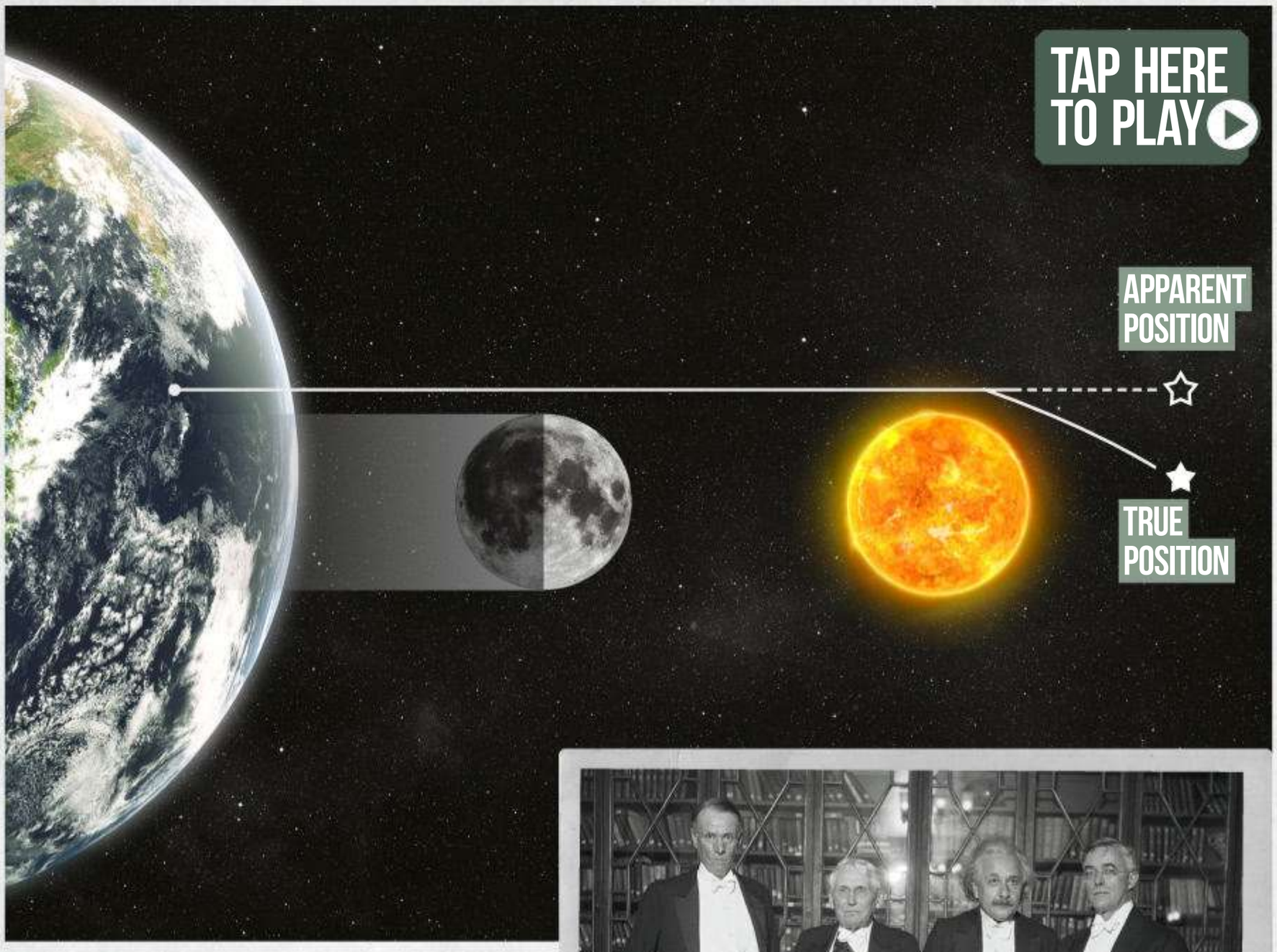
he had been in a relationship since 1912. In 1921 he won the Nobel Prize in Physics for his work on the photoelectric effect, though the committee members also mentioned his "services to theoretical physics" when presenting their award.

The decision to give Einstein the award was controversial because the brilliant physicist was Jewish and a pacifist. Anti-Semitism was on the rise at the time, and relativity was not yet seen as a proven theory. It ended up being attacked by other scientists, such as the Hungarian-born German physicist Philipp Lenard, who labelled Einstein's work as "Jewish physics". It meant that the 1921 award was deferred for a year, leaving out relatively in favour of Einstein's explanation of the photoelectric effect. It wasn't a pleasant period, and it would only get worse.

Although Einstein was a professor at the University of Berlin for a time, he fled Germany with Löwenthal in 1933, during the rise of Adolf Hitler. He renounced his German citizenship and moved to the US to become a professor of theoretical physics at Princeton, becoming a US citizen in 1940. During this era, other researchers were creating a revolution by reformulating the rules of the smallest known entities in existence. The laws of quantum mechanics had been worked out by a group led by the Danish physicist Niels Bohr, and Einstein was intimately involved with their efforts.

Bohr and Einstein famously clashed over the latter's qualms regarding quantum mechanics. Bohr and his cohorts proposed that quantum particles behaved according to probabilistic laws, which Einstein found unacceptable, quipping that "God does not play dice with the universe". He later clarified his comment, saying he didn't believe in a personal God and that dice was a reference to quantum mechanics. Bohr's views eventually came to dominate much of contemporary thinking about quantum mechanics.

After he retired in 1945, Einstein spent most of his later years working on a method to unify gravity with electromagnetism in what's known



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as a unified field theory. The effort stumped the physicist, who died of a burst blood vessel near his heart on 18 April 1955. Einstein's body was cremated, and his ashes were spread at an undisclosed location. But a doctor performed an unauthorised craniotomy before this, removing and saving Einstein's brain. The brain has been the subject of many tests over the decades, which suggested that it had extra folding in the grey matter, the site of conscious thinking. In particular, there were more folds in the frontal lobes, which have been tied to abstract thought and planning. However, drawing any conclusions about intelligence based on a single specimen is problematic, according to Eric H. Chudler, a neuroscientist at the University of Washington.

In addition to his incredible legacy regarding relativity and quantum mechanics, Einstein conducted lesser known research into a refrigeration method that required no motors, moving parts or coolant. He was also a tireless anti-war advocate, helping to found the Bulletin of the Atomic Scientists, an organisation dedicated to warning the public about the dangers of nuclear weapons.

Einstein's theories concerning relativity have so far held up spectacularly as predictive models. Astronomers have found that, as the legendary physicist anticipated, the light of distant objects is lensed by massive, closer entities – a phenomenon known as gravitational lensing, which has helped our understanding of the universe's evolution.

In 2016, the Advanced Laser Interferometer Gravitational-Wave Observatory also announced the first-ever direct detection of gravitational waves, created when massive neutron stars and black holes merge and generate ripples in the fabric of space-time. It adds up to an enviable body of work, and his life was befitting of one of his famous quotes: "Try not to become a man of success," he said, "but rather try to become a man of value." He succeeded in being both.

Adam Mann
Space science journalist
Mann is a journalist specialising in astronomy and physics. His work has appeared in *Wired*, *Nature*, *Science*, *New Scientist* and many other places.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

Top: Gravity from massive objects distorts light, moving the position of stars behind large masses

Above: Einstein stands with other Nobel Prize in Physics winners

1912
Became a professor of theoretical physics at ETH.

1913
Worked on his new theory of gravity, believing current understanding to be wrong.

1914
Became professor of theoretical physics at the University of Berlin.

1915
Published his general theory of relativity.

1917
Published his first paper on cosmology.

1919
His general theory of relativity was proven by a solar eclipse, raising his profile.

1920
Anti-Semites attacked Einstein and his work.

1922
Worked on unified field theory and won the Nobel Prize for his work on quantum theory.

1927
Developed the foundations of quantum mechanics with Niels Bohr.

1928
Worked on a unified field theory, but suffered a heart illness.

1933
Left Nazi Germany for the US and took up a post at the Institute for Advanced Study in Princeton, New Jersey.

1939
Warned President Franklin D. Roosevelt that Germany could be building an atomic bomb.

1940
Awarded US citizenship.

1952
Turned down becoming president of the new State of Israel.

1955
Died in Princeton, New Jersey, of heart failure.

MYSTERY OF EMPTY-SKY BURSTS CRACKED

Scientists finally have an explanation for the most energetic explosions in the universe

Reported by Brandon Specktor

Gamma-ray bursts (GRBs) are the brightest, most energetic blasts of light in the universe. Released by immense cosmic explosions, a single GRB is capable of shining about a million trillion times brighter than the Sun. And, for the most part, scientists can't explain why they happen. Part of the problem is that all known GRBs come from very far away – usually billions of light years from Earth. Sometimes a GRB's home galaxy is so far-flung that the burst's light appears to come from nowhere at all, briefly blipping out of the black, empty sky and vanishing seconds later.

These 'empty-sky' gamma-ray bursts have presented an ongoing cosmic mystery for more than 60 years. But a new study offers a compelling explanation for the bursts' origins. According to the researchers – who modelled the interactions between gamma rays and other powerful energy sources, such as cosmic rays – all those nebulous empty-sky bursts could be the result of massive stellar explosions in the discs of distant galaxies. "We modelled the gamma-ray emissions from all the galaxies in the universe and found that it's star-forming galaxies that produce the majority of gamma-ray radiation," Matt Roth, an astrophysicist at Australian National University in Canberra, said.

Astronomers favour two leading explanations for the empty-sky gamma-ray mystery. In one explanation, the rays occur when gas falls into the supermassive black holes that sit at the centres of all galaxies in the universe. In this scenario, as gas particles get sucked into the black hole, a small fraction escape, instead radiating in large, near-light-speed jets of matter. It's thought that these powerful jets could be responsible for gamma-ray bursts.

The other explanation points to stellar explosions called supernovae. When large stars run out of fuel and erupt in these violent supernova explosions, they can send nearby particles blasting away at near light speed. These highly energetic particles, called cosmic rays, may then collide with other particles sprinkled through the gassy hinterland between stars, producing gamma rays.

In the new study, the researchers focused on that second explanation by modelling the interactions between cosmic rays and interstellar gas in various types of star-forming galaxies. They found that the rate of gamma-ray emissions was influenced by several key factors, including the size of the galaxy, the rate of star formation – which affects the rate of supernovae – and the initial energy of the cosmic rays created by each supernova.

> "IT'S STAR-FORMING GALAXIES THAT PRODUCE THE MAJORITY OF GAMMA-RAY RADIATION"
>
> MATT ROTH

Left: Gamma rays (magenta) blast out of the Cassiopeia A supernova remnant in this composite satellite image

Once the team had a model that predicted the rate of GRBs for every size of galaxy, they compared their model to a real survey of gamma-ray radiation compiled by NASA's Fermi Gamma-ray Space Telescope. They found that their calculations fit with the observations, and that supernovae in star-forming galaxies could explain most, if not all, empty-sky GRBs.

"It's a significant milestone to discover the origins of these gamma-ray emissions, solving a mystery of the universe astronomers have been trying to decipher since the 1960s," Roth said. Black holes are probably still responsible for some of the gamma rays that our satellites pick up, the researchers added, but when it comes to the mysterious empty-sky GRBs, the hungry holes are simply not necessary; exploding stars in faraway corners of the universe are sufficient to explain the phenomenon.

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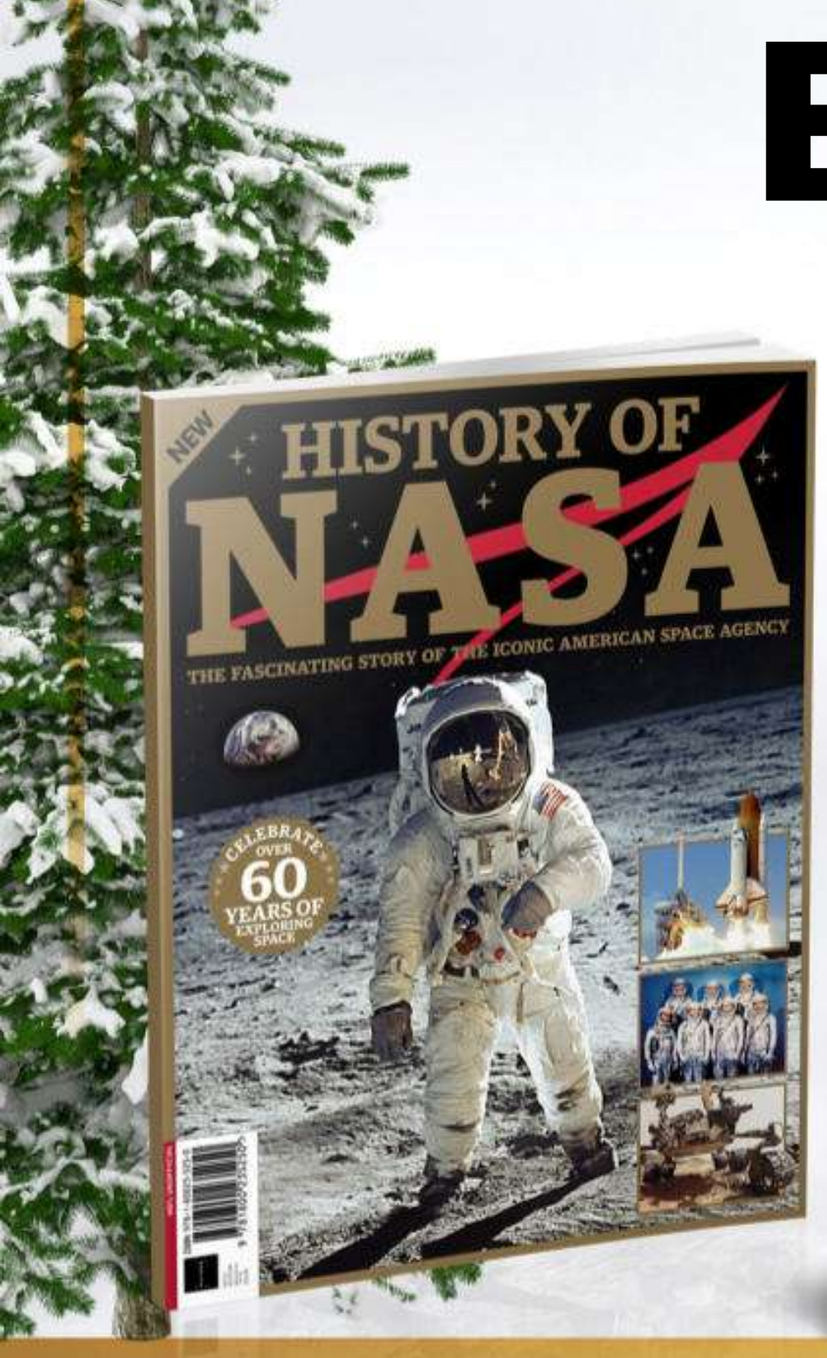
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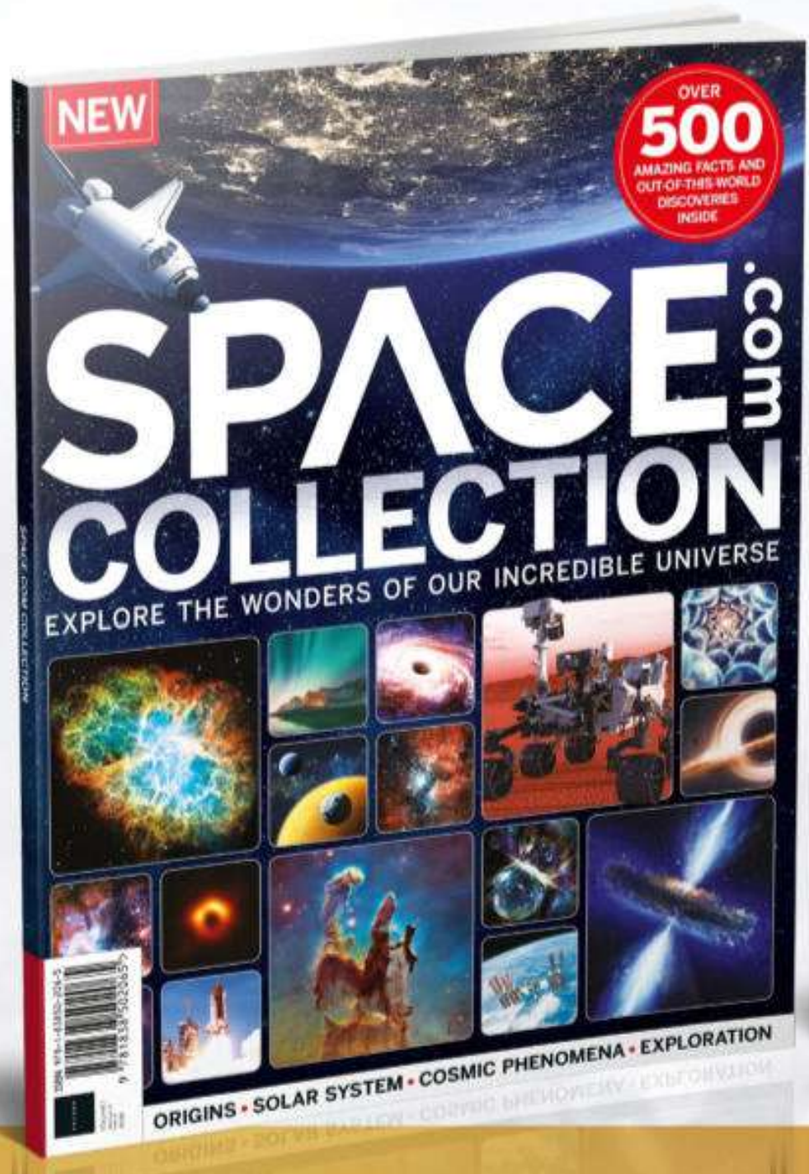
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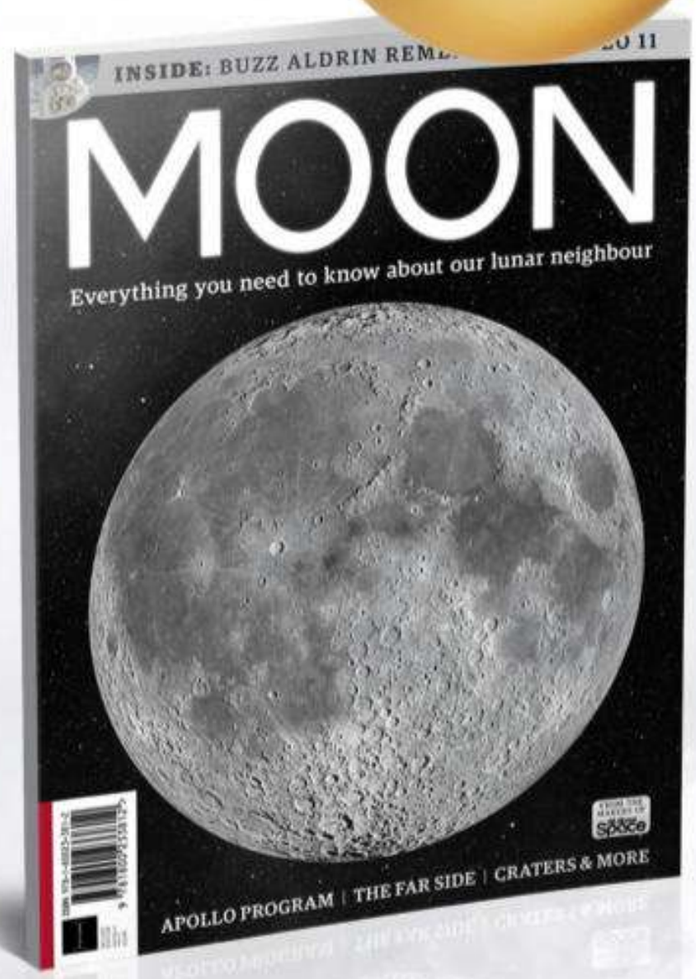
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ARE WE CLOSER TO REVEALING THE SECRETS OF PLANET FORMATION?

Data gathered by a host of radio dishes perched high in the Chilean desert teases apart the mysteries of how worlds form

Reported by Meghan Bartels

The Atacama Large Millimeter/submillimeter Array (ALMA) specialises in studying protoplanetary discs, the mess of material that surrounds young stars and eventually comes together to build planets. While scientists do plenty of work analysing already-formed exoplanets, studying protoplanetary discs offers an opportunity to see all those ingredients mixed up and spread out.

A new set of 20 papers shares results from a research program called Molecules with ALMA at Planet-forming Scales (MAPS), which uses the powerful facility to study protoplanetary discs. One of the new papers maps the presence of more than a dozen organic molecules throughout five different protoplanetary discs. Organic molecules, which contain carbon, are of particular interest to scientists trying to understand how life begins.

"These planet-forming discs are teeming with organic molecules, some of which are implicated in the origins of life here on Earth," Karin Öberg, an astronomer at the Harvard-Smithsonian Center for Astrophysics (CfA) and principal investigator for MAPS, said. "This is really exciting. The chemicals in each disc will ultimately affect the type of planets that form, and determine whether or not the planets can host life."

The maps don't only show that organic compounds exist in protoplanetary discs; they show that the distribution of such ingredients varies. That means two planets forming in different regions of the same protoplanetary disc could end up with vastly different supplies of these compounds. "Our maps reveal it matters a great deal where in a disc a planet forms," Öberg said. "Two planets can form around the same star and have very different organic inventories, and therefore predispositions to life."

In addition to locating different ingredients, the research also identified compounds built with deuterium, which is a form of hydrogen

© Getty

Main: New findings highlight the distribution of matter before planets form

twice as heavy as the most commonly found flavour of the element. The research suggested that deuterium levels vary across a disc, with much less of the atom found closer to the star at the heart of the disc.

Scientists were also able to detect the very earliest signs of a planet coalescing out of a disc. That's usually very difficult - the same dust and debris that forms the disc itself also blocks the tiny baby stages of planets. "It's like trying to see a fish underwater," said Richard Teague, lead of a segment of the MAPS project. "We know they're there, but we can't peer that far down. We have to look for subtle signs on the surface of the water, like ripples and waves."

Another segment of the MAPS research focused on the precursors of massive Jupiter-like planets, in which elements like carbon and oxygen seemed to be much rarer than compounds like methane. "Our findings suggest that many gas giants may form with extremely oxygen-poor (carbon-rich) atmospheres, challenging current expectations of planet compositions," Arthur Bosman, an astronomer at the University of Michigan and lead author of one of the papers, said.

"THESE PLANET-FORMING DISCS ARE TEEMING WITH ORGANIC MOLECULES, SOME OF WHICH ARE IMPLICATED IN THE ORIGINS OF LIFE" KARIN ÖBERG

The new research shows that there's plenty more to learn about what surrounds young stars, how planets form and what that means for the universe and life's prospects in it.

"We're hoping to use ALMA to search for the next stepping stones of chemical complexity in these discs," said John Ilee, an astronomer at the University of Leeds and lead researcher on a new MAPS study. "If we detect them, then we'll be even closer to understanding how the raw ingredients of life can be assembled around other stars."

DO PARALLEL UNIVERSES EXIST?

SCIENCE FICTION LOVES A GOOD MULTIVERSE STORY. BUT COULD WE REALLY BE IN ONE?

Reported by Vicky Stein

Our universe is unimaginably big. Hundreds of billions - if not trillions - of galaxies spin through space, each containing billions or trillions of stars. Some researchers studying models of the universe speculate that the universe's diameter could be 7 billion light years across. Others think it could be infinite. But is it all that's out there?

Science fiction loves the idea of parallel universes and the thought that we might be living just one of an infinite number of possible lives. Multiverses aren't reserved for science fiction, though. Real scientific theory explores - and in some cases supports - the case for universes outside, parallel to or distant from but mirroring our own. Multiverses and parallel worlds are often argued in the context of other major scientific concepts like the Big Bang, string theory and quantum mechanics.

Parallel universes

Around 13.8 billion years ago, everything we know of was an infinitesimal singularity. Then, according to the Big Bang theory, the universe burst into action, inflating faster than the speed of light in all directions for a tiny fraction of a second. Before 10^{-32} seconds had passed, the universe had exploded outwards to 10^{26} times its original size in a process called cosmic inflation. And that's all before the actual expansion of matter that we usually think of as the Big Bang itself, which was a consequence of all this inflation. As the inflation slowed, a flood of matter and radiation appeared – creating the classic Big Bang fireball – and began to form the atoms, molecules, stars and galaxies that populate the vastness of space that surrounds us.

That mysterious process of inflation and the Big Bang have convinced some researchers that multiple universes are possible, or even very likely. According to theoretical physicist Alexander Vilenkin of Tufts University in Massachusetts, inflation didn't end everywhere at the same time. While it ended for everything that we can detect from Earth 13.8 billion years ago, cosmic inflation continues in other places. This is called the theory of eternal inflation. And as inflation ends in a particular place, a new bubble universe forms, Vilenkin said in 2011.

> "THE REST OF THE MULTIVERSE IS BARREN, BUT NO ONE IS THERE TO COMPLAIN ABOUT THAT"
>
> ALEXANDER VILENKIN

Those bubble universes can't contact each other because they continue to expand indefinitely. If we were to set off for the edge of our bubble, where it might butt up against the next bubble universe over, we'd never reach it because the edge is zipping away from us faster than the speed of light, and faster than we could ever travel. But even if we could reach the next bubble – according to eternal inflation and string theory – our familiar universe, with its physical constants and habitable conditions, could be totally different from the hypothetical bubble universe next to our own.

"This picture of the universe, or multiverse, as it's called, explains the long-standing mystery of why the constants of nature appear to be fine-tuned for the emergence of life," Vilenkin wrote. "The reason is that intelligent observers exist only in those rare bubbles in which, by pure chance, the constants happen to be just right for life to evolve. The rest of the multiverse remains barren, but no one is there to complain about that." Vilenkin's explanation implies that in some of the infinite bubble universes outside our own, there could be other intelligent observers. But in every instant that passes we get farther away from them, and we will never intersect.

Other researchers base their ideas of parallel universes on quantum mechanics, the mathematical description of subatomic particles. In quantum mechanics, multiple states of existence for tiny particles are all possible at the same time – a 'wave function' encapsulates all of those possibilities. However, when we actually observe subatomic particles, we only ever observe one of the possibilities. According to the Copenhagen interpretation of quantum mechanics, we observe an outcome when the wave function 'collapses' into a single reality, 'forcing' the subatomic particle to pick a state.

The many-worlds theory proposes instead that every time one state, or outcome, is observed, there is another 'world' in which a different quantum outcome becomes reality. This is a branching arrangement in which, instant by instant, our perceived universe branches into near-infinite alternatives. Those alternate universes are completely separate and unable to intersect, so while there may be uncountable versions of you living a life that's slightly – or wildly – different from your life in this world, you'd never know it.

The many-worlds theory is the most 'courageous' take on the quandary of quantum mechanics, physicist Sean M. Carroll wrote in his book, *Something Deeply Hidden: Quantum Worlds and the Emergence of Spacetime*. He also argued that it's the most straightforward theory, although not without its wrinkles. One of those wrinkles is that the many-worlds idea is not really falsifiable. This is an extremely important component of scientific thought, and is the way the scientific community develops ideas that can be explored with observation and experimentation. If there's no opportunity to find evidence against a theory – or indeed for it – that's bad for science as a whole.

Some physicists believe in a flatter version of multiple universes. That is, if the universe we live in goes on forever, there are only so many ways that the building blocks of matter can arrange themselves as they assemble across infinite space. Eventually, any finite number of particle types must repeat a particular arrangement. Hypothetically, in a big enough

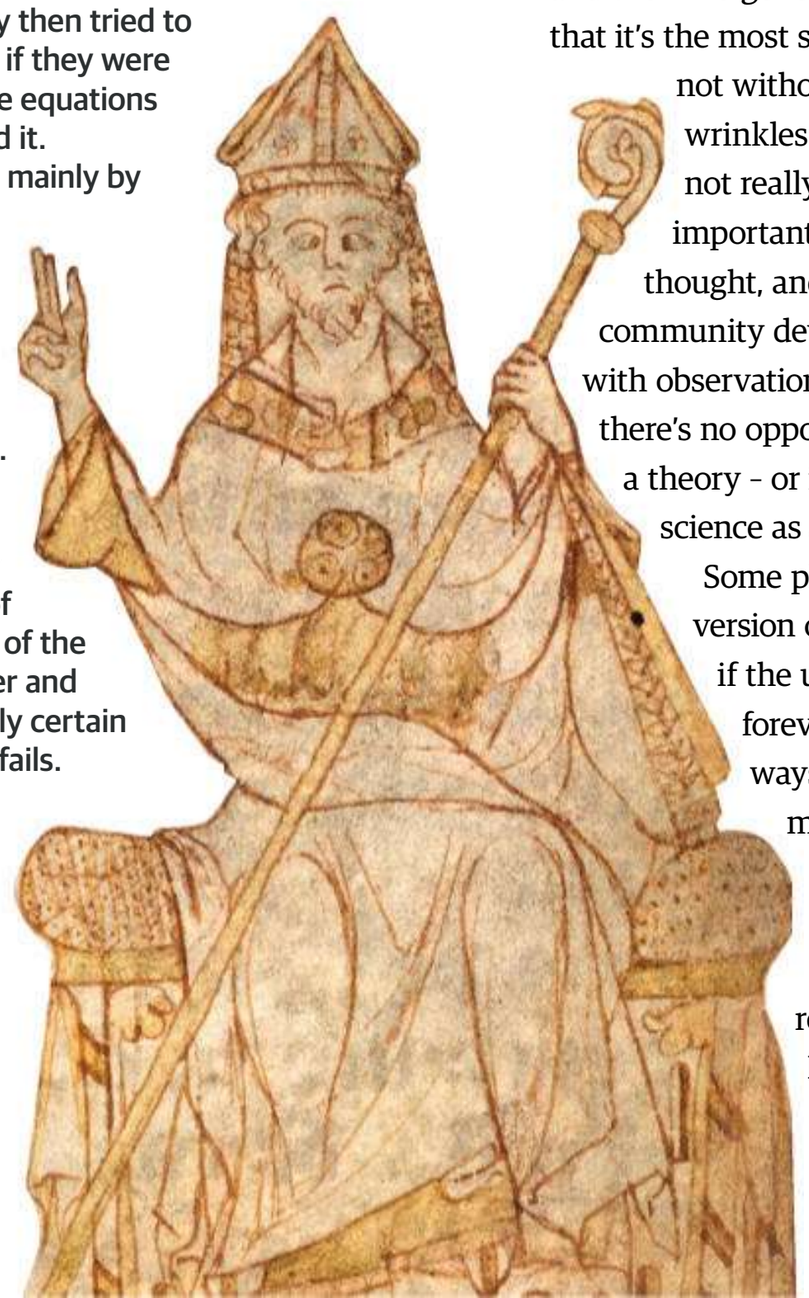
HOW A MEDIEVAL PHILOSOPHER DREAMED UP THE 'MULTIVERSE'

The idea that our universe may be one among many has intrigued modern cosmologists for some time. But this concept might have appeared, albeit unintentionally, back in the Middle Ages. When scientists analysed a Latin text and applied modern mathematics to it, they found hints that the English philosopher who wrote it in 1225 was already toying with concepts similar to the multiverse. Scientists translated the text – *De Luce*, which means 'On Light', by philosopher Robert Grosseteste – into English. They then tried to understand what he was aiming to explain, and wrote down his ideas as if they were modern mathematical equations. A team used a computer to solve these equations and to see whether they explained the universe as Grosseteste imagined it.

In his time, the dominant cosmological model was the one developed mainly by Aristotle. He postulated that there were nine planets (spheres), one inside the other, with Earth at the centre. Grosseteste assumed that the universe was born from an explosion that pushed everything, matter and light, out from a single point – an idea strikingly similar to the modern Big Bang theory. However, Grosseteste's reasoning only works if there's the right number of properly ordered celestial spheres, and this only happens in simulations if there are very specific starting points.

The medieval philosopher realised this problem. To deal with it, he added an extra reason to explain why there were exactly nine celestial spheres plus one – an 'imperfect' Earth. His explanation was remarkably similar to the reasoning applied in modern cosmology. Today, the laws of general relativity and quantum mechanics are used to explain the origin of the cosmos, but they don't tell us the amounts of normal matter, dark matter and dark energy in the universe. In other words, current models work for only certain specific values, and if the values are chosen at random, the explanation fails.

To satisfy these conditions, some physicists suggest that we live in a multiverse – that there is not one universe, but an infinite number of them. In this way, any outcome can be accounted for, if not in ours, then in a neighbouring universe. In the same way, if the parameters in Grosseteste's model are modified, there will be a different number of spheres around Earth. Although *De Luce* never mentions the term 'multiverse,' Grosseteste seems to realise that the model does not predict a unique solution and that there are many possible outcomes.



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HOW TO BUILD A MULTIVERSE

Could black holes birth new universes?

1 BLACK HOLE
One theory is that black holes are responsible for creating new universes.

2 RIP
This theory suggests the singularity can rip a hole in the universe, perhaps when it collapses.

3 EVENT HORIZON
In this region of the black hole, gravity is so intense that nothing can escape its pull.

4 SINGULARITY
Inside a black hole is a pea-sized singularity, where gravity is essentially infinite.

5 FEEDING
One version suggests that material sucked in by the black hole 'feeds' the new universe.

6 INFLATION
The new universe rapidly expands in a period we call cosmic inflation.

7 DEATH
The black hole collapses, leaving behind the new universe.

8 PHYSICS
Each new universe would form with its own laws of physics, and only some would survive.

9 CONTROVERSY
This is only a theory at the moment. There is no direct evidence that this actually happens.

TAP HERE TO PLAY

WELCOME TO THE MULTIVERSE

1 BIG CRUNCH
Universes that fall back on themselves end in a similar state to the Big Bang. Cosmologists speculate that this kind of 'Big Crunch' could give rise to another universe in turn.

2 BIG BANG
Universes begin with a Big Bang, which may be triggered by a chance fluctuation in the quantum foam, or a collision between branes.

3 CLOSED UNIVERSE
Development of an individual universe is determined by fundamental properties such as the strength of gravity and the amount of matter contained within it.

4 RAW MATERIAL
The background fabric of the multiverse would be beyond time and space, perhaps in the form of many-dimensional 'branes', or as an all-pervading 'quantum foam'.

5 SHORT LIVED
Some universes may be so massive that the expanding force of dark energy is never able to take hold, so they collapse back onto themselves, ending in a 'Big Crunch'.

6 PERPETUAL EXPANSION
In our universe, an expansive force called dark energy seems to have grown stronger over time, overwhelming the attraction of gravity to produce an ever-growing cosmos.

7 PERPETUAL SLOWDOWN
If the forces of expansion and contraction are precisely balanced, a universe may expand ever more slowly, but will never come to a halt.

8 LONG-LIVED UNIVERSE
With less matter and mass, a universe might be able to expand to a huge size and exist for trillions of years before eventually collapsing back.

© Tobias Roetsch

Left: Perhaps a universe could exist that is an exact mirror image of our own

space, those particles must repeat arrangements as large as entire solar systems and galaxies. So your entire life might be repeated elsewhere in the universe, down to what you ate for breakfast yesterday. At least, that's thought to be the theory.

But if the universe began at a finite point – as nearly every modern physicist agrees it did – an alternate version of you likely doesn't exist, at least according to astrophysicist Ethan Siegel. As Siegel explains, "the number of possible outcomes from particles in any universe interacting with one another tends towards infinity faster than the number of possible universes increases due to inflation. So what does this mean for you?" Siegel posits. "It means it's up to you to make this universe count."

In a relatively recent addition to the pantheon of multiverse theories, researchers from the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, have proposed that the universe began at the Big Bang, and on the opposite side of the Big Bang timeline, stretching backwards in time, a universe once existed that was the exact mirror image of our own.

"Instead of saying that there was a different universe before the Big Bang, we're saying that the universe before the Big Bang is actually, in some sense, an image of the universe after the Big Bang," Neil Turok, a Perimeter Institute researcher, says. That means everything – protons, electrons and even actions like cracking an egg – would be reversed. Antiprotons and positively charged electrons would make up atoms, while eggs would uncrack and make their way back inside chickens. Eventually, that universe would shrink down, presumably to a singularity, before expanding out into our own universe. Seen another way, both universes were created at the

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"WE'RE SAYING THAT THE UNIVERSE BEFORE THE BIG BANG IS ACTUALLY, IN SOME SENSE, AN IMAGE OF THE UNIVERSE AFTER THE BIG BANG

NEIL TUROK

Big Bang and exploded simultaneously backwards and forwards in time.

Countless works of myth and fiction draw from ideas of parallel universes and the multiverse. Overlapping worlds make appearances in Norse mythology, as well as in Buddhist and Hindu cosmology. The idea of multiple universes coming into contact showed up in print as early as Edwin A. Abbott's novella *Flatland: A Romance of Many Dimensions* in 1884, and can still be seen in recent media, such as the 2016 Marvel film *Doctor Strange*. An entire genre of Japanese light novels, manga, anime and video games, called isekai, deals with characters transported to parallel worlds. Nearly every *Star Trek* series incorporates some form of mirror universe, and the 2009 reboot film starring Chris Pine and Zachary Quinto took subsequent *Star Trek* movies into an entirely new timeline that explicitly branches off from the original series. Many comics, as well as their corresponding movies, delve deeply into the idea of parallel worlds. Recent Marvel storylines – in film, TV and in print – DC's *Flashpoint* arc and 2018's *Into the Spider-Verse* all explore multiple universes and the intersections between them.

Above: This deep-field image captured by Hubble shows a small area of space in the constellation of Fornax. It shows thousands of galaxies and is one of the deepest images of the universe ever captured

Vicky Stein
Science journalist
Vicky holds a degree in science communication and has worked as a reporter for *Stanford News Service*, **space.com** and **LiveScience**

WHAT HAPPENS IN OTHER UNIVERSES?

Physicists have contemplated different levels of multiverse

LEVEL 1
WHAT HAPPENS INSIDE THIS UNIVERSE?

Everything that happens in the observable universe is repeated an infinite number of times. Also, every possible combination of events can unfold an infinite number of times. There are planets where you don't exist, but also those where you do and you're the ruling monarch of the universe or a sentient slug.

LEVEL 2
WHAT HAPPENS INSIDE THIS UNIVERSE?

Most agree that the laws of physics and the properties of particles would differ in each universe. The majority would be unlike ours, but there will be exact copies, meaning lots of identical yous. Others will be near copies in which famous historical events unfolded differently.

LEVEL 3
WHAT HAPPENS INSIDE THIS UNIVERSE?

As each new universe branches off from a previous one, the laws of physics are consistent across the Level 3 multiverse. However, it's a one-way journey. You're forever marching onwards and cannot return to a universe you were in previously, so no time travel to the past.

LEVEL 4
WHAT HAPPENS INSIDE THIS UNIVERSE?

The creators of the universe have set it up. Perhaps they have experimented with the strength of forces and masses of particles until they found the right settings in order to create a universe with stars, planets and life. There would be no connection between universes in this scenario.

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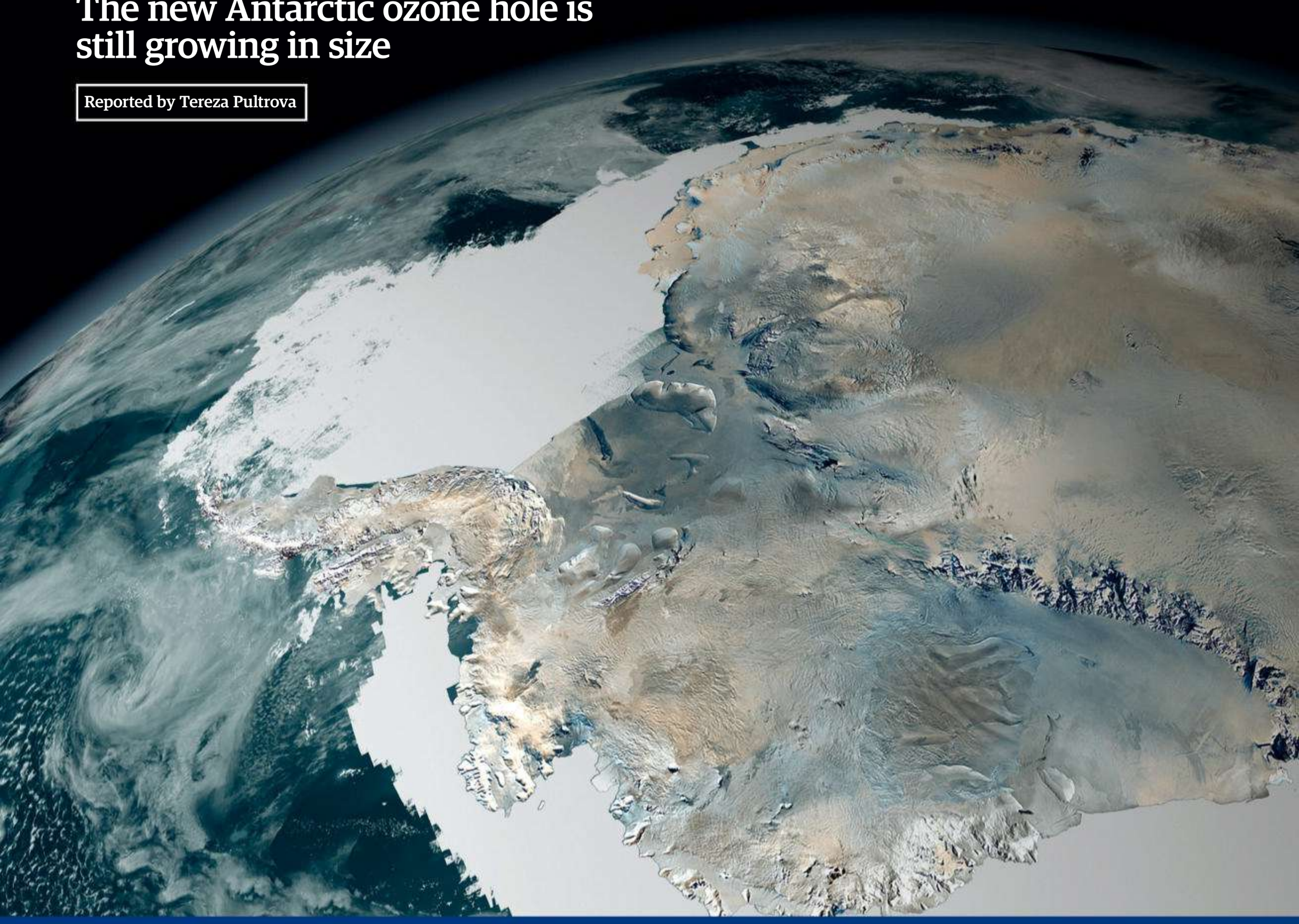
Focus on

2021'S GIANT OZONE HOLE LIKELY DUE TO CLIMATE CHANGE

The new Antarctic ozone hole is still growing in size

Reported by Tereza Pultrova



A giant ozone hole opened up over Antarctica this year. Already larger than the entire ice-covered continent, the ozone hole has surpassed the size of 75 per cent of ozone holes measured since 1979, and is still growing. Scientists believe climate change might be the cause.

The Montreal Protocol, signed in 1987, is frequently described as the world's greatest success story in battling human-caused destruction of the environment. The agreement banned harmful chlorofluorocarbons and other substances known to destroy the protective ozone layer, which absorbs damaging ultraviolet radiation coming from the Sun. Concentrations of the damaging substances in the atmosphere have levelled off since the protocol came into force and are slowly decreasing, providing the foundation for the layer's gradual healing. But worsening climate change is now slowing down the recovery.

"It's still a matter of research to fully understand the connection between the ozone recovery and climate change, but we know that there is a coupling between ozone depletion and temperature," said Vincent-Henri Peuch, head of the European Union's Copernicus Atmosphere Monitoring Service, which released the data on 16 September. While temperatures at the planet's surface are increasing, the stratosphere, where the protective ozone shield resides, is cooling down. The stratosphere, the layer of Earth's atmosphere about 10 to 50 kilometres (6.5 to 30 miles) in altitude, is where polar stratospheric clouds form in winter. Scientists know that these clouds provide the perfect chemical environment for the damaging chlorine and bromine-based substances to do their destructive work. They also know that the colder the temperature of the stratosphere, the more polar stratospheric clouds tend to form, Peuch said.

"Sometimes the ozone hole is small because there are no polar stratospheric clouds, and sometimes, when there are many, it tends to be bigger," Peuch said. "With more polar stratospheric clouds, chlorine and other harmful substances can work more effectively and cause more damage, even if their concentrations are decreasing."

> "THERE IS A COUPLING BETWEEN OZONE DEPLETION AND TEMPERATURE"
>
> VINCENT-HENRI PEUCH

Left: The new hole is among the 25 per cent largest in recorded history

When the Montreal Protocol was signed, scientists predicted that the ozone layer would fully recover by 2060, Peuch added. However, recent measurements suggest that this healing process is slowing down, and that a full recovery could be expected no earlier than 2070.

But climate change isn't entirely responsible; some countries continue using and releasing the banned substances illegally. "In 2018, high levels of banned chlorofluorocarbons were detected in the atmosphere that were eventually traced to China," Peuch said. "If such illegal emissions go undetected for some time, that could really compromise the whole process because the chlorine and bromine in the atmosphere could stop levelling off and stabilising, or increase."

Peuch says that the size of the ozone hole varies substantially year to year, and that trends are hard to pick out. This year the ozone hole already covers an area of 22 to 23 million square kilometres (8.5 to 8.8 million square miles), just 2 million square kilometres (700,000 square miles) short of the 2006 record level of 25 million square kilometres (9.7 million square miles). Peuch predicts the hole will continue to grow until early October, when temperatures in the Southern Hemisphere will start to rise. 2020 also saw a very large – and the longest lasting – ozone hole that only closed in late December. In 2019, on the other hand, the ozone hole was the smallest in recorded history.

The Copernicus Atmosphere Monitoring Service uses data from several satellites which detect ozone in the stratosphere by measuring the passage of the ultraviolet and infrared components of sunlight through the atmosphere. The less ozone present, the more ultraviolet and infrared light gets through. Sophisticated computer models then combine the data, just like in weather forecasting.

Peuch said researchers are still trying to unpack the connection between climate phenomena experienced on Earth and the processes in the stratosphere. It is therefore impossible to say whether this year's unprecedented heatwaves in many parts of the world and the gaping ozone hole might be connected.

OUR MISSIONS TO THE MOON

HOW SPACECRAFT HAVE HELPED US PAVE THE WAY IN EXPLORING OUR NEAREST NEIGHBOUR

Written by Andrew May

© Getty

IMPACTORS, LANDERS AND ROVERS

Some Moon missions are designed to study it from a distance, taking photographs and collecting other data as they fly past or orbit it. But we'll start by looking at spacecraft that were designed to descend all the way to the surface, whether in a gentle soft landing – permitting an extended science mission – or a high-velocity impact, in which all the science has to be done on the way down.

Since the dawn of the Space Age, more than a hundred spacecraft have left Earth en route to the Moon. Not all of them made it, especially in the early years, but the ones that did embody some of the most amazing feats of human ingenuity ever seen.

The story of lunar exploration splits into two distinct phases. The first, lasting from the late 1950s to mid-1970s, was dominated by the rivalry between the United States and Soviet Union, known as the Space Race. With a quickfire string of firsts from both nations, this race to the Moon had an undeniably political dimension to it, but it yielded scientific rewards, too. The Apollo and Luna missions told scientists more about our nearest neighbour in space than we ever knew before, blazing the trail for all the orbiters, landers and rovers – whether on the Moon or other planets – since.

After a pause lasting over a decade, the second phase kicked off in the 1990s – and it's still going strong today. With a stronger focus on science, this phase is also notable for its international flavour, with spacecraft from Japan, Europe, China, India and Israel all playing a part. A key goal of these missions has been to locate water and other resources on the Moon – holding out the promise of an exciting future in which humans establish a long-term presence there.

- NASA
- SOVIET UNION
- ISRO
- CNSA
- SPACEIL
- JAXA
- ESA
- SUCCESSFUL
- UNSUCCESSFUL

"THIS RACE TO THE MOON HAD AN UNDENIABLY POLITICAL DIMENSION TO IT, BUT IT YIELDED SCIENTIFIC REWARDS, TOO"

FIRST ON THE MOON

Less than a year after launching Sputnik, the first satellite, in October 1957, the Soviets were aiming for the Moon. After several false starts, the nation finally made it with Luna 2 in September 1959. This was a deliberate crash landing; the 390-kilogram spacecraft had no braking rockets or landing legs, and the main payload simply consisted of two grenade-like spheres that scattered Soviet emblems over the lunar surface. All said, it was an astonishing achievement for the 1950s.

AR SCAN HERE

- Luna E-1 No. 1
- Luna E-1 No. 2
- Luna E-1 No. 3
- Luna 1
- Luna E-1A No. 1
- Luna 2
- Ranger 3
- Ranger 4
- Ranger 5
- Luna E-6 No. 2
- Luna E-6 No. 3
- Luna 4
- Ranger 6
- Luna E-6 No. 6
- Luna E-6 No. 5
- Ranger 7
- Ranger 8
- Kosmos 60
- Ranger 9
- Luna E-6 No. 8
- Luna 5
- Luna 6
- Luna 7
- Luna 8
- Luna 9
- Surveyor 1
- Surveyor 2
- Luna 13
- Surveyor 3
- Surveyor 4
- Surveyor 5
- Surveyor 6
- Surveyor 7
- Luna E-8 No. 201
- Luna E-8-5 No. 402
- Luna 15
- Apollo 11
- Kosmos 300
- Kosmos 305
- Apollo 12
- Luna E-8-5 No. 405
- Apollo 13
- Luna 16
- Luna 17 & Lunokhod 1
- Apollo 14
- Apollo 15
- Luna 18
- Luna 20
- Apollo 16
- Apollo 17
- Luna 21 & Lunokhod 2
- Luna 23
- Luna E-8-5M No. 412
- Luna 24
- Moon Impact Probe
- LCROSS
- Chang'e 3 & Yutu
- Chang'e 4 & Yutu-2
- Beresheet
- Chandrayaan-2
- Chang'e 5

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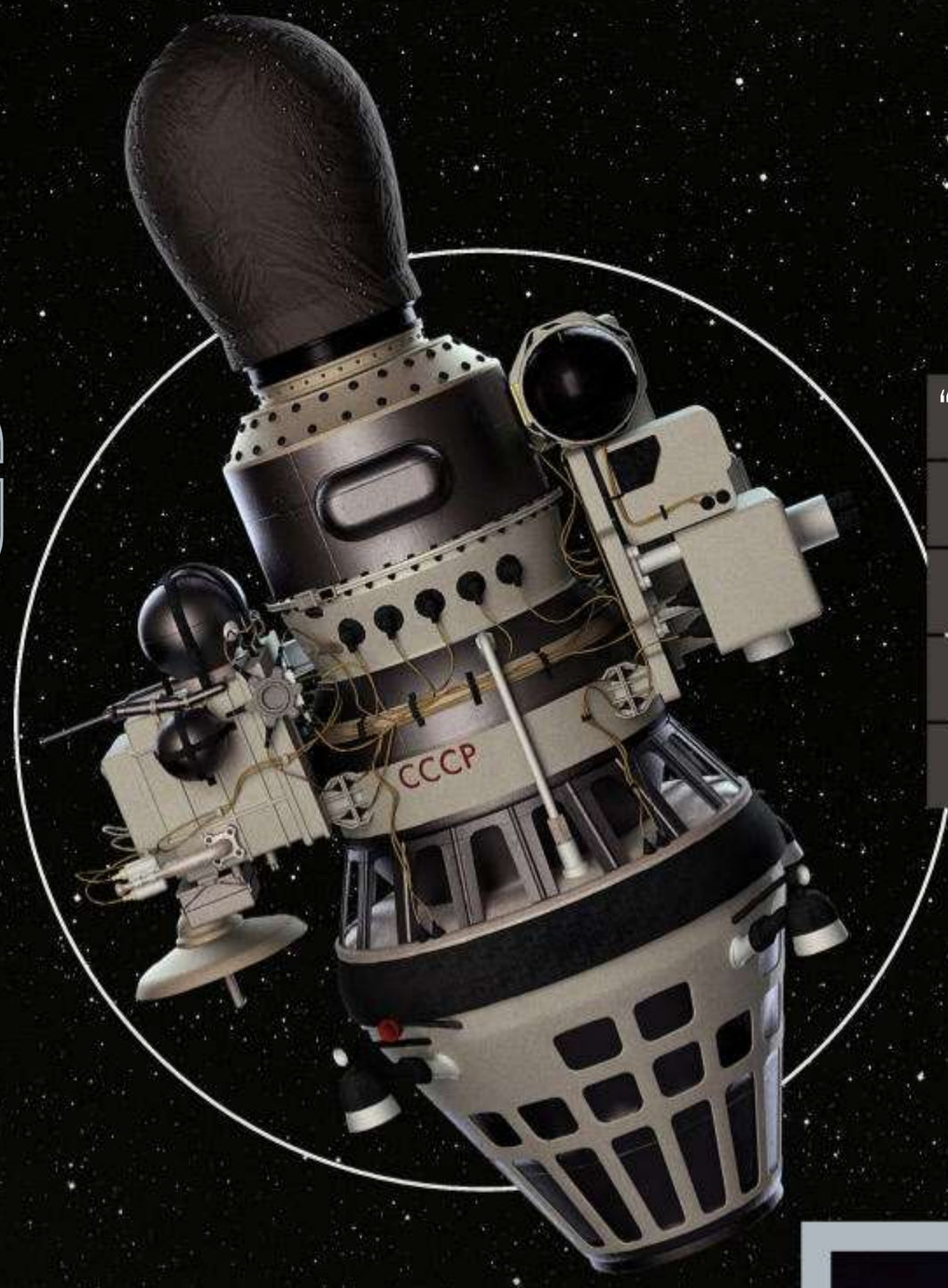
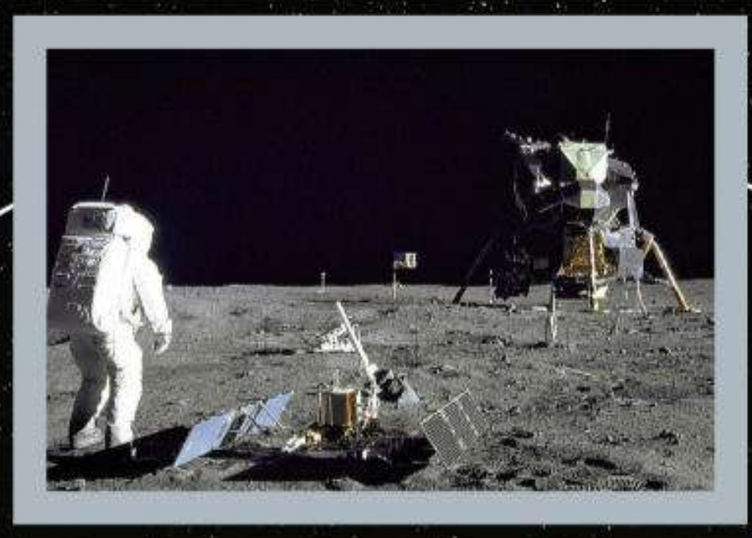
SOFT LANDING

A high-speed impact is one thing, but landing in one piece and surviving long enough to carry out a scientific mission is a technical challenge of a different order. It wasn't accomplished until 3 February 1966, when the Soviets made it into the record books again with the Luna 9 lander. The soft landing was achieved by a small capsule, just 99 kilograms in mass, which was ejected by the main spacecraft just before touchdown. The capsule went on to take the first photographs from the lunar surface, successfully transmitting them back to Earth.



"THE SOFT LANDING WAS ACHIEVED BY A SMALL CAPSULE, JUST 99 KILOGRAMS IN MASS"



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THE BIG ONE

To many people, *the* Moon mission – the one that springs instantly to mind – was Apollo 11 in July 1969. This put the first humans, Neil Armstrong and Buzz Aldrin, onto the lunar surface, and then returned them safely to Earth – a monumental feat by the United States that was repeated five more times over the next few years. From a technical point of view, the Apollo missions were extremely complex, involving both a regular space capsule called the Command Module, which remained in lunar orbit with another crew member on board, and a specially designed Lunar Module to descend to the surface.

© NASA

AR SCAN HERE

© Getty

ROBOT EXPLORER

Though they had aspirations to do so, the Soviets never put humans on the Moon. Instead they concentrated on robotic missions, such as Luna 17 in November 1970, which delivered the first remote-control rover, Lunokhod 1, to the Moon's surface. The rover explored its surroundings for ten months – a mission duration that would have been impossible for human astronauts in the 1970s. In addition to doing important lunar science, Lunokhod 1 also paved the way for today's Mars rovers.

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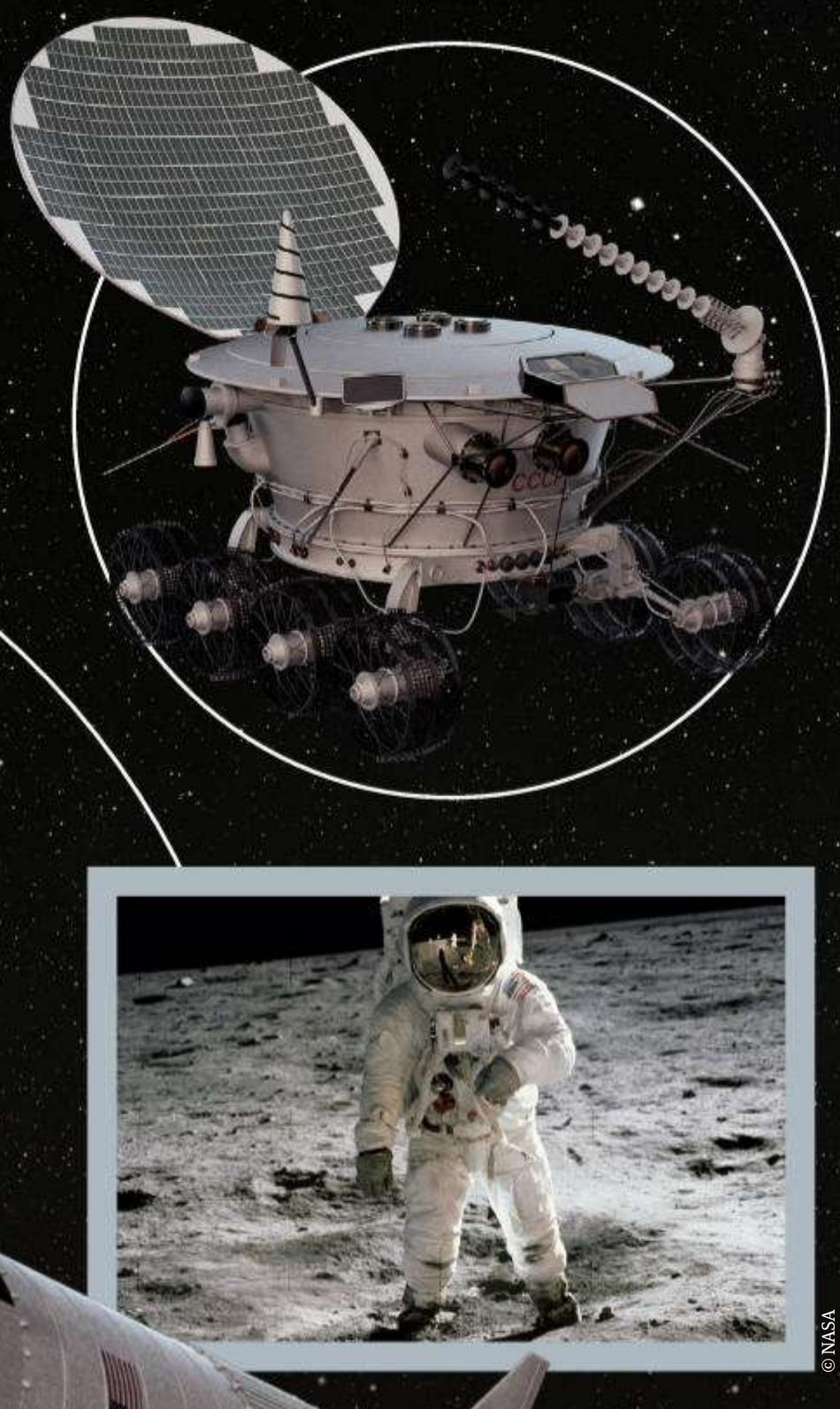


ON THE FAR SIDE

When China embarked on its Lunar Exploration Program, it was playing a rapid game of catch-up with what had come before. The country's first orbiter, first lander and first rover all came within a few years of each other. Then, on 3 January 2019, China achieved something that had never been done before: dropping a lander, Chang'e 4, and rover, Yutu-2, onto the far side of the Moon. That's the side we never see from Earth – or from a spacecraft's perspective, the side that has no line-of-sight communication with Earth. To solve that problem, China had to place a relay satellite, called Queqiao, at the Earth-Moon Lagrange point, which has a clear view of both.

© NASA

PRIVATE ENTERPRISE

The missions described so far were all designed, operated and paid for by government-owned agencies. The first attempt to put a privately developed spacecraft on the Moon wasn't until 2019, when a small lander called Beresheet almost pulled it off. The lander made it to the lunar surface, but having lost control on the way down it was a crash, not the intended soft landing. The brainchild of an Israeli nonprofit organisation called SpaceIL, Beresheet's operators are hoping that its successor will have better luck.

AR SCAN HERE

ORBITERS AND FLYBYS

Orbiters and flyby missions may not arouse quite the same excitement as a landing, but from space tortoises to finding ice on the Moon, they've been just as important to the advancement of science.

- Pioneer 0
- Pioneer 1
- Pioneer 2
- Pioneer 3
- Pioneer 4
- Pioneer P-1
- Luna 3
- Pioneer P-3
- Luna E-3 No. 1
- Luna E-3 No. 2
- Pioneer P-30
- Pioneer P-31
- Zond 3
- Kosmos 111
- Luna 10
- Lunar Orbiter 1
- Luna 11
- Luna 12
- Lunar Orbiter 2
- Lunar Orbiter 3
- Lunar Orbiter 4
- Lunar Orbiter 5
- Luna 14
- Zond 5
- Zond 6
- Apollo 8
- Apollo 10
- Zond 7
- Zond 8
- Luna 19
- Luna 22
- Hiten & Hagoromo
- Clementine
- Lunar Prospector
- SMART-1
- SELENE
- Chang'e 1
- Chandrayaan-1
- Lunar Reconnaissance Orbiter
- Chang'e 2
- ARTEMIS P1 and P2
- Ebb and Flow (GRAIL)
- LADEE
- Chang'e 5-T1
- Queqiao

ESCAPE FROM EARTH

Before a spacecraft can get to the Moon, or anywhere else beyond Earth orbit, it has to achieve an escape velocity of 40,230 kilometres (25,000 miles) per hour. After several false starts, the first US space probe to do this was Pioneer 4 in March 1959. This was the first lunar 'flyby' mission, passing the Moon at a distance of around 60,000 kilometres (37,000 miles).

THE MOON'S FIRST SATELLITE

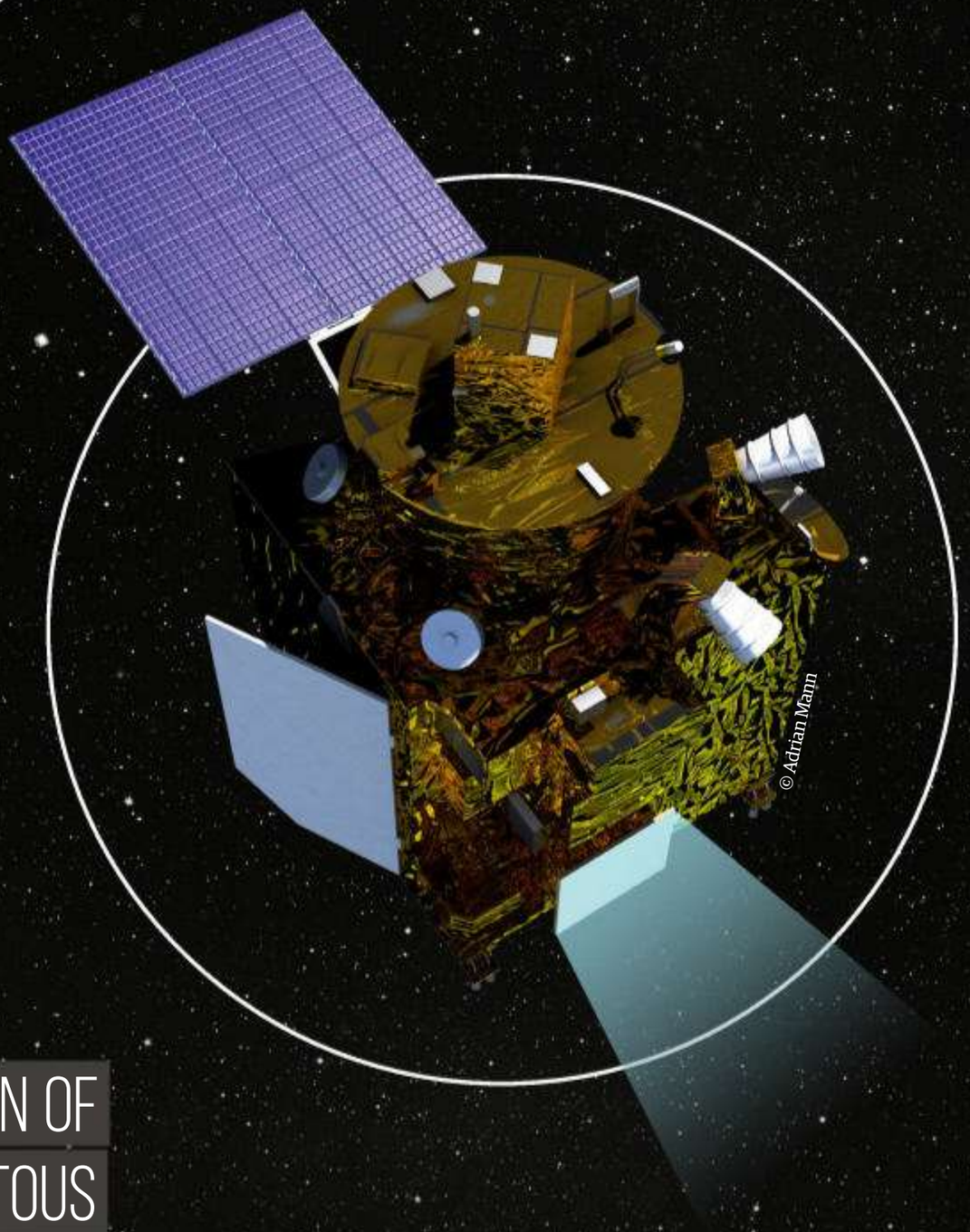
On 3 April 1966, the Soviet Union scored another Moon first when Luna 10 entered lunar orbit. Not only was it the first spacecraft to do this, it was the first to orbit any astronomical body other than Earth. The advantage of an orbiter over the earlier flybys and impactors is that it can make close-range scientific observations over a much longer period. Luna 10's batteries lasted 56 days in orbit, during which it sent back valuable data on the Moon's composition, gravity field and lack of atmosphere or magnetic field.

TRANSLUNAR TORTOISES

The first spacecraft to swing around the Moon without entering orbit, then return to Earth, was the Soviet Union's Zond 5 in September 1968. It was also the first lunar mission to carry passengers – albeit non-human ones. This 'biological payload' included two Russian tortoises. They both survived the journey, splashing down in the Indian Ocean six days after leaving Earth.

FINDING WATER ICE

Of all the countries that have sent spacecraft to the Moon, India has the distinction of making a truly momentous scientific discovery on its very first mission: Chandrayaan-1. The spacecraft entered lunar orbit on 8 November 2008, also carrying the small Moon Impact Probe, which it fired six days later into Shackleton crater near the lunar south pole. When data from the impact was examined, it strongly indicated the presence of water – a discovery confirmed by a NASA instrument also on board Chandrayaan-1.



"INDIA HAS THE DISTINCTION OF MAKING A TRULY MOMENTOUS SCIENTIFIC DISCOVERY"

OVERSHADOWED PIONEERS

The Apollo 11 astronauts weren't the first humans to reach the Moon; they were preceded by two test flights that orbited the Moon without landing. The first of these, in December 1968, was Apollo 8. Its crew – Frank Borman, Jim Lovell and Bill Anders – became the first humans to travel beyond Earth orbit. Although soon overshadowed by Apollo 11, Apollo 8 was still a tremendous achievement that hasn't been repeated since the end of the Apollo program. While in lunar orbit, the crew took the famous 'Earthrise' photo, which became one of the most iconic images of the Space Age.

WHAT NEXT?

Looking at the dozens of future Moon missions still in the planning stages, two trends are clear. First, there's the increasing internationalism of the field, with Canada, Turkey, the United Arab Emirates, South Korea and even a resurgent Russia keen to embark on their own programs of lunar exploration. The second even-more-exciting trend is the ever-growing prospect of a return to crewed Moon missions in the near future. Here's a quick rundown of the strongest contenders:

SPACE TOURISM

SpaceX's Starship, currently under development, should make sightseeing trips around the Moon – following the same there-and-back route taken by Zond 5's tortoises – a real possibility for super-rich tourists. The first one has already booked a ticket: Japanese billionaire Yusaku Maezawa.

CHINESE AMBITIONS

With its successful rover and sample-return missions, China now looks to be the world leader in robotic Moon missions. But the country's plans don't stop there, and it's already developing a new generation of crewed spacecraft that could take Chinese astronauts to the Moon in the 2030s.

A GATEWAY IN SPACE

NASA has plans to construct a smaller scale version of the International Space Station to place in lunar orbit. Called Gateway, the first elements of this lunar space station are scheduled to be launched by a SpaceX Falcon Heavy rocket in 2024. Gateway is an enabler for a much more ambitious NASA project: the Artemis lander.

THE HEIRS TO APOLLO

The aim of the Artemis program is to land the next astronauts – including the first woman and the first person of colour – on the Moon by 2024. That's a tight timescale, but the plan is for the landing to be preceded by just two test flights: an uncrewed circumlunar mission and a crewed one. The third flight will be the landing itself, using a variant of SpaceX's Starship.

Instant expert

WHAT CAN WE DO WITH A CAPTURED ASTEROID?

Asteroids could provide us with rare resources

Asteroids have more than enough gold, plus other precious metals, to provide a few lifetimes' worth of fortunes. But there are plenty of other reasons asteroids are valuable. But how do we get these metals from these faraway asteroids? Perhaps the best way is to bring the space rocks to Earth. Most of the metals we use in our everyday lives are buried deep within the Earth. And we mean deep: when our young planet was still molten, almost all of the heavy metals sank to the core, which is pretty hard to get to. The accessible veins of gold, zinc, platinum and other valuable metals instead came from later asteroid impacts on Earth's surface.

Those asteroids are the fragmented remains of almost-planets, but they contain all the same mixtures of elements as their larger planetary cousins – and you don't have to dig down into their cores to get it. But the main problem with asteroids is that they are far away. To launch from Earth's surface and go into orbit, a rocket needs to change its velocity from zero to eight kilometres (five miles) per second. To rendezvous with an average asteroid, the rocket has to change its velocity by another 5.5 kilometres (3.4 miles) per second. That requires almost as much fuel as the launch itself, which the rocket would have to carry as dead weight, adding to the already-high cost of trying to set up a remote mining operation in the first place. And once the asteroid was mined, asteroid prospectors would be faced with a difficult choice: They could try to refine the ore right there on the asteroid, which would entail setting up an entire refining facility, or ship the raw ore back to Earth, with all the waste that would involve.

AR SCAN HERE

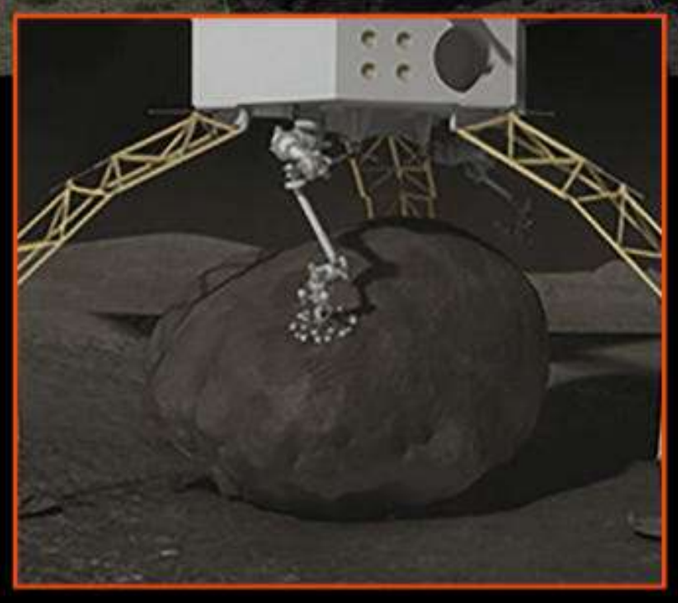
© Adrian Mann

BRINGING HOME THE GOODS

Instead of trying to mine a distant asteroid, how about we bring the asteroid to Earth? NASA's ill-fated Asteroid Redirect Mission (ARM) was an attempt to do just that. The goal of the mission was to grab a four-metre (13-foot) boulder from a nearby asteroid and return it to cislunar space – between the orbits of Earth and the Moon – where we could then study it at our leisure. To move the boulder, ARM would use solar electric propulsion, with solar panels absorbing sunlight and converting it into electricity. That electricity would power an ion engine. It wouldn't be fast, but it would be efficient – and it would eventually get the job done. Unfortunately, in 2017, NASA cancelled ARM. Some of the critical technologies wound up in other projects, like the OSIRIS-REx mission to the asteroid Bennu, and NASA continues to investigate and use ion engines.

WITHIN ARMS REACH

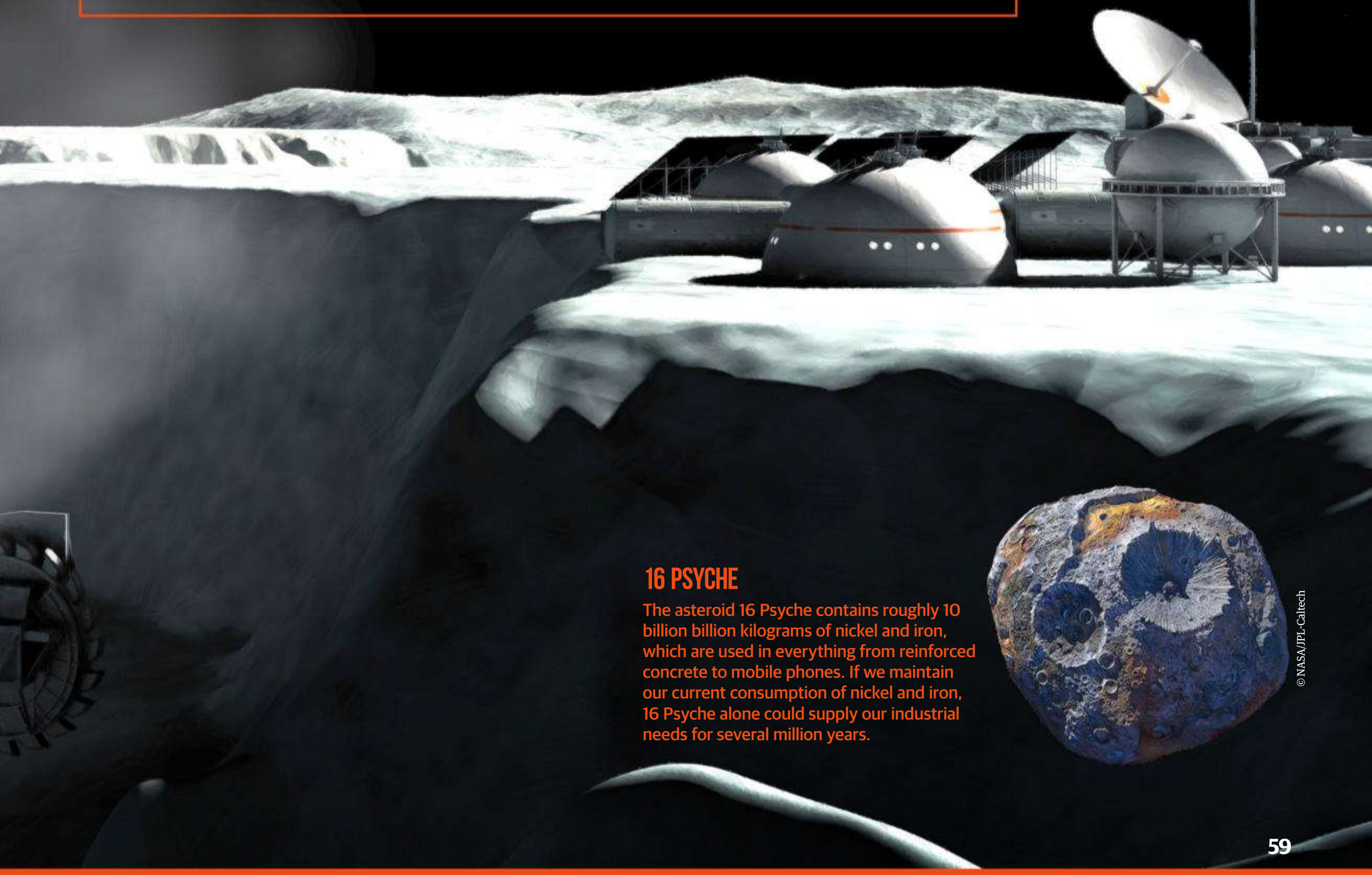
A recent study found a dozen potential asteroids, ranging from 2 to 20 metres (6.6 to 66 feet) across, that could be brought into near-Earth orbit with a change in velocity of less than 500 metres (1,640 feet) per second. The solar electric propulsion schemes cooked up for ARM would be perfectly capable of that, although it would take a while. Once an asteroid is in near-Earth space, many of the difficulties of asteroid mining are significantly reduced. A cislunar asteroid would be much easier to study and much easier to test different mining strategies on.



x2 Images © NASA

BIO
PAUL M. SUTTER

Sutter is a research professor in astrophysics at the Institute for Advanced Computational Science at Stony Brook University and a guest researcher at the Flatiron Institute in New York City. He is also the author of two books: *Your Place in the Universe* and *How to Die in Space*.



16 PSYCHE

The asteroid 16 Psyche contains roughly 10 billion billion kilograms of nickel and iron, which are used in everything from reinforced concrete to mobile phones. If we maintain our current consumption of nickel and iron, 16 Psyche alone could supply our industrial needs for several million years.

© NASA/JPL-Caltech

MYSTERIES OF THE UNIVERSE

DOES OUR MILKY WAY HAVE ANOTHER ARM?

ASTRONOMERS IN CHINA HAVE OBSERVED A LARGE FILAMENT OF GAS AND DUST AT THE OUTER EDGE OF OUR GALAXY, BUT WHAT MIGHT IT BE?

© Getty

Reported by David Crookes

Observing the extent of the Milky Way is not the easiest of tasks. The main problem is that Earth is located inside its disc, so perhaps the best way of seeing our galaxy as a whole would involve stepping foot inside a spaceship, flying far away and turning around to see the Milky Way in its entire glory.

That's not going to happen any time soon, so astronomers have sought other means to determine its three-dimensional structure, size, volume and whatever is contained within. In 1914, for instance, Harlow Shapley observed pulsating low-mass stars called Cepheid variables and worked out the distance between them to get a better idea of our galaxy's size.

AR SCAN HERE

CATTAIL BY NUMBERS

3,590
Minimum light years in length

16,300
Most likely length in light years

68,000
Distance from Earth in light years

675
Width in light years

65,000
Mass in Suns

–150
Mean velocity in kilometres per second

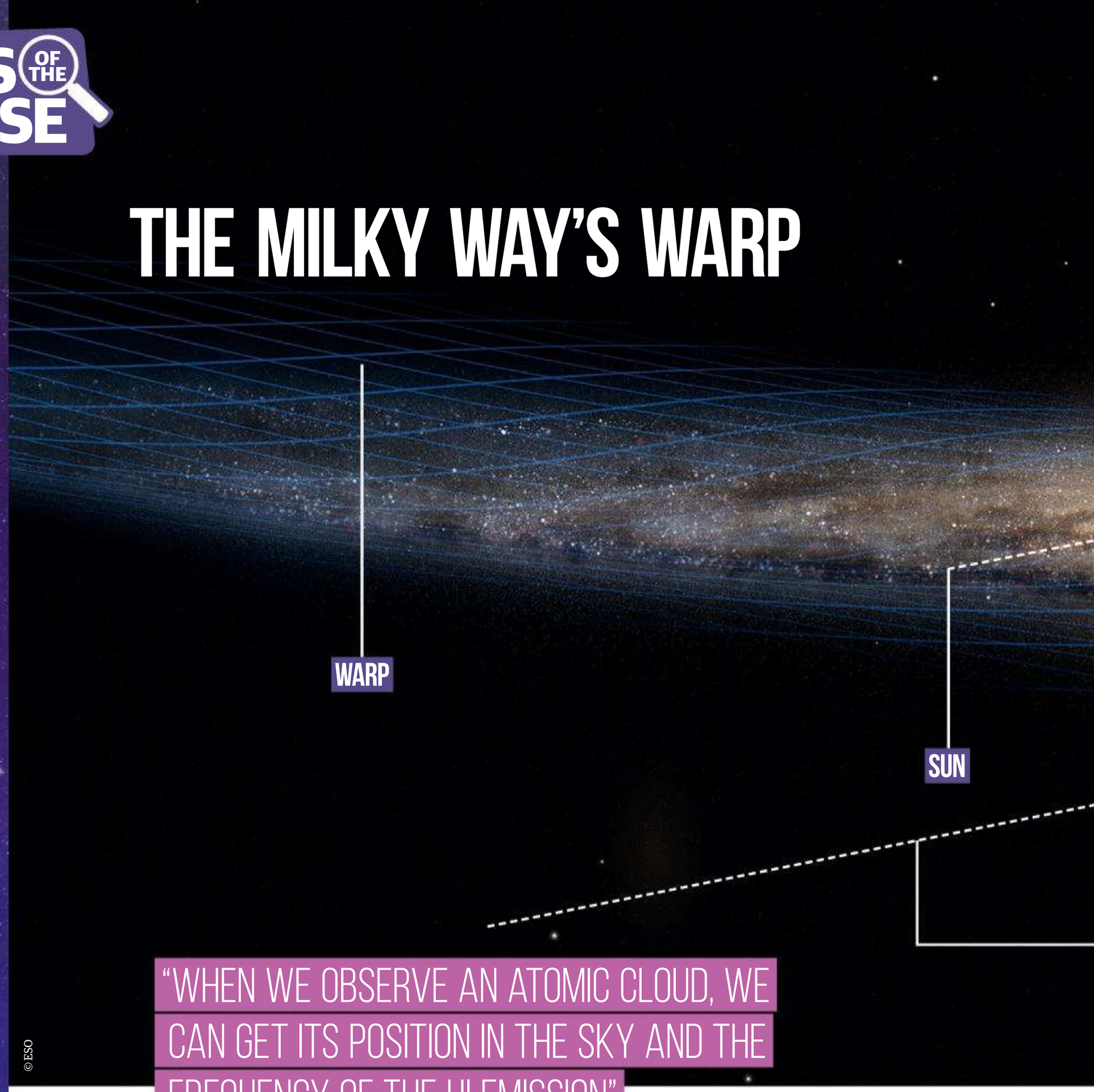
2019
Year Cattail was observed

3
Number of telescopes used to gather data

5:1
Aspect ratio

FOUR
confirmed spiral arms of the Milky Way

THE MILKY WAY'S WARP



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"WHEN WE OBSERVE AN ATOMIC CLOUD, WE CAN GET ITS POSITION IN THE SKY AND THE FREQUENCY OF THE HI EMISSION"

CHONG LI

Below: There's a strong possibility that Cattail is the largest gas filament discovered in the Milky Way

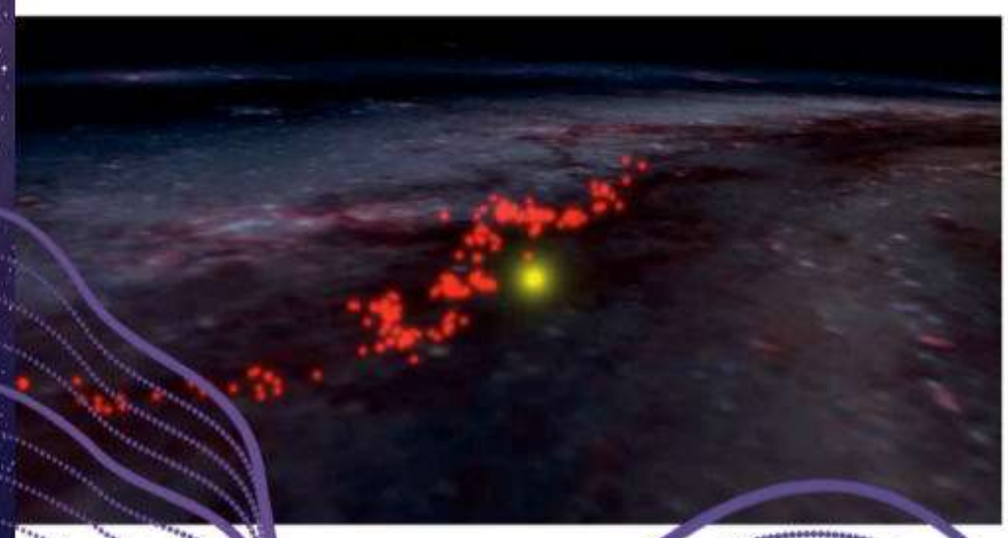
He also discovered that the Sun was not at the centre of our galaxy as previously thought, but 26,000 light years away from it near the central plane – and yet he still believed that what we know today as the Milky Way was the entire universe. It took calculations by astronomer Edwin Hubble to persuade him that there are instead many galaxies which make up the universe, and even then the admission only came reluctantly.

Since then, more refined methods of observing the Milky Way have followed, including studying the amount of hydrogen in the galaxy and the distances to its sources. It was studies such as this which found that we live within a barred spiral galaxy, and if there's one thing we're certain of, it's that it has four known spiral arms.

Infrared images from NASA's now-retired Spitzer Space Telescope have shown that two of these arms are major ones: Scutum-Centaurus and Perseus. Both are attached to the ends of a thick central bar, and they have densities of young and old stars.

The two other arms – Norma and Sagittarius – were also once thought to be major, but they are now deemed less distinct. With pockets of star-forming activity and filled with gas, these are referred to as minor arms.

But what if there are more? Can we really be sure that we've seen all there is to see? The swift answer to this is an emphatic 'no', and a recent discovery is proving very exciting indeed. In China, astronomers at Nanjing University have been making use of the Five-hundred-meter Aperture Spherical Telescope (FAST), the world's largest single-dish radio observatory, based in Guizhou in the south of the country.



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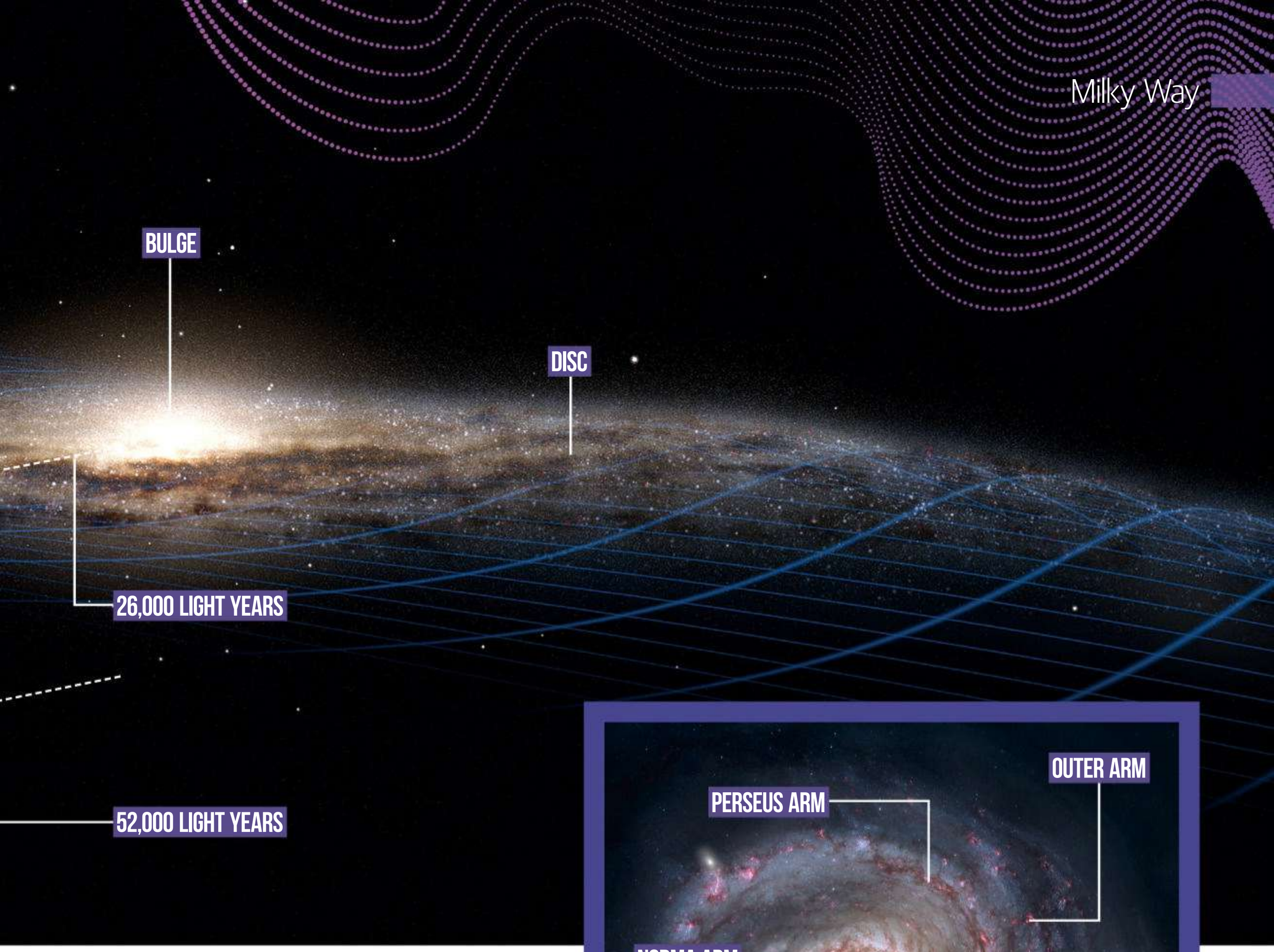

© NASA

Right: There are four known arms of the Milky Way. The two major ones are attached to the ends of the central bar, and two minor ones are located in between

The huge dish is capable of collecting radio waves from an area double the size of its nearest challenger and predecessor, the Arecibo Observatory in Puerto Rico, and astronomers have used it to study a region of sky called Cygnus-X – an active star-forming region some 4,500 light years away which is the strongest source of X-rays visible from Earth.

"Cygnus-X is one of the most active high-mass star-forming regions in the Milky Way," says Dr Chong Li, leader of the new study, explaining why he and his small team began observing it. "High-mass stars play a key role in galactic evolution by ionising and dynamically affecting the interstellar medium, and also by chemically enriching heavy elements.

"They are the principal source of ultraviolet radiation, heavy elements and stellar feedback. But because of the short evolutionary time scale, large extinction and remote distance, our understanding of high-mass star formation is still sketchy. That's despite a large number of observational studies towards Cygnus-X being performed by various tracers."

By looking at this part of the sky, the astronomers were primarily aiming to observe atomic gas. "Atomic gas in this region is not well studied," Li continues. "Stars form in molecular clouds, while molecular clouds form in atomic clouds. We performed an observation of neutral atomic hydrogen in the sky region of Cygnus-X using FAST. This will help us to understand the physical conditions of atomic gas in this region."

As they were observing the gas, however, they found that the region was hiding a little secret. During observations, the Nanjing scientists were able to pick up on cold gas clouds containing hydrogen situated behind the star-forming region. To do this, they made use of FAST's ability to make observations through the radio portion of the electromagnetic spectrum, and what stood out starkly was a massive, long curl of gas. "FAST enabled us to observe the atomic gas with a better

Source: Wikipedia Commons © Diceman Stephen

Left: The Parkes Observatory in Australia was completed in 1961; it was used for the HI4PI sky survey, which shows the concentration of stars in the Milky Way

angular resolution – that is, in greater detail," Li tells **All About Space**. "In addition, a large effective aperture means FAST has high sensitivity, which makes it a suitable facility to search for remote structures with weak emissions."

By looking for subtle differences in the light emitted by hydrogen, researchers were able to get a handle on the astonishing properties of the long curl of gas. Not only did they work out that it's 71,750 light years from the centre of the Milky Way based on its velocity, they could then determine that it's 3,600 light years in length and about 675 light years wide. Even then, this distant gas filament may be bigger still. But what could it be?

Having named it Cattail – so called because it's long and thin – and taking into account its position on the outer edge of the Milky Way, the astronomers believe it could be a previously unknown arm of our galaxy, potentially making it the fifth known arm. If so, it's hugely significant, and it would prove to be a major breakthrough.

"To put this into perspective, the farthest spiral arm, which we have long known about, is located about 49,000 light years from the galactic centre, while the farthest filament in previous studies is located about 39,000 light years from the galactic centre," says Li. "That is what we knew about our Milky Way Galaxy, so we were excited when we found that Cattail is located 71,750 light years from the galactic centre. Such a large filamentary structure was never expected to be located at this extreme location."

This has caused the scientists to go into full swing to find out more. They've already been

FAST RESULTS

China's massive telescope took five years to complete, but it's made a speedy impact

1 FEED CABIN

A cabin weighing 30 tonnes and containing the feed antenna is suspended on cables 140 metres (459 feet) above the dish. Winches can be used to steer the instrument, allowing signals to be received from many different directions.

2 REFLECTING SURFACE

The surface is made up of 4,450 triangular panels made of perforated aluminium, forming a reflecting surface 500 metres (1,640 feet) in diameter that focuses on the antenna. Usable space is about 300 metres (984 feet), and it can observe sources within 40 degrees of the zenith.

3 SUPPORT TOWERS

The six support towers are about 100 metres (328 feet) in height; they contain the winch servomechanisms as well as a counterweight to assist in cable tensioning.

4 A LONG PERIOD

Nicknamed Tianyan, or 'Heaven's Eye', the Five-hundred-meter Aperture Spherical Telescope – located in a natural basin in Guizhou, China – began trial operations in September 2016. It became fully operational in January 2020.

5 RADIO SILENCE

To ensure radio silence within five kilometres (three miles), it's said that 8,000 people were moved from their homes in eight villages and given new accommodation. Its remote location meant China struggled for a while to recruit people to run it.

able to supplement their findings from FAST with data from other sources, and this is providing more clues as to what – and how big – this giant gas filament could be. For example, the Chinese scientists have been using data from the HI4PI full-sky survey, which was released in 2016. This important endeavour mapped the detailed structure of neutral atomic hydrogen across the Northern and Southern Hemispheres using two fully steerable radio telescopes: the 64-metre (210-foot) Parkes Observatory in Australia and the 100-metre (328-foot) Effelsberg in Germany.

When taking the HI4PI data into consideration, the scientists say it's not impossible that Cattail could be as long as 16,000 light years. It's also likely to contain a mass roughly equal to 65,000 Suns. There's no doubt that this is one huge space structure – potentially far larger than a swooping stream of gas called the Radcliffe wave that's some 9,000 light years long.

But that's not all. What makes this long curl of gas even more intriguing is that most of the Milky's Way's bulk tends to be closer to the centre of the galaxy, and yet Cattail is three times farther out from the galactic centre than Earth. This means that Cattail holds the record of being both the largest and the most distant gas filament ever discovered.

To find out more details, the scientists are currently in the process of further mapping this part of the sky using the data from HI4PI. "When we observe an atomic cloud, we can get its position in the sky and the frequency of the HI emission," Li explains of the process involved.

"You may have heard of the Doppler effect: the whistle is higher pitched when the train comes towards you, while it's lower pitched when the train leaves. That frequency can be converted into velocity. According to the rotation curve of the Milky Way, we can convert the velocity to distance. Finally, we can derive its physical size and position in the Milky Way. We use HI4PI because the FAST observation didn't cover the complete structure of Cattail."

Such mapping is helping to fill in the gaps of knowledge. "Our understanding of the outermost disc is still sketchy, and we have no idea about the properties of spiral arms if they are located in the extreme outer galaxy," Li continues. "A river may look like a brook at the source and end locations, and that's the same with an arm and a filament; we can't determine the nature of Cattail with the existing data.

"In general, a spiral arm should have a larger length and origin from the galactic bar.

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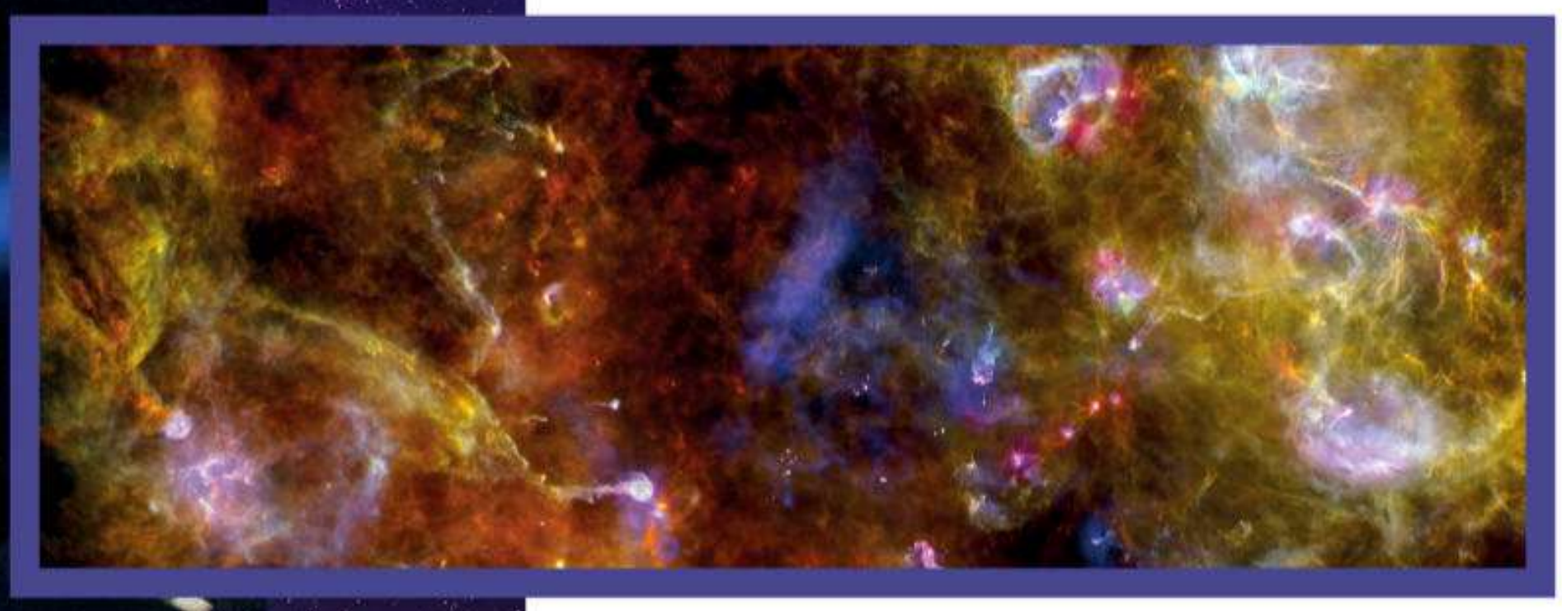
Below: While observing the Cygnus-X region, the Chinese astronomers discovered clouds of hydrogen gas far behind it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"WE USE HI4PI BECAUSE THE FAST OBSERVATION DIDN'T COVER THE COMPLETE STRUCTURE OF CATTAIL"

CHONG LI

WHAT COULD CATTAIL BE?

The theories for this huge newfound structure

A NEW SPIRAL ARM

Gas filaments are associated with spiral arms, but they tend to be closer to the centre of a galaxy, where most of its bulk resides. The fact Cattail has formed so far out is puzzling, requiring further investigation, so it can't be said for certain that it's part of a spiral arm. What's more, Cattail's shape isn't warped at the edges, as would be expected of an arm.

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A BRANCH OF A KNOWN ARM

Could the gas filament branch off from one of the four known spiral arms? It's possible, and the astronomers at Nanjing University are considering this. More observations would be needed to see where the connection is made, but branches are not uncommon. The Earth is on a branch of the Sagittarius Arm called Orion Spur.

© Getty

IT'S A STANDALONE STRUCTURE

Could Cattail simply be a giant gas filament that's formed in that particular far-out region of the Milky Way? It's something that's being considered, although how it formed so far out needs to be investigated if this is indeed the case. Astronomers at least know it's part of the Milky Way and not in another galaxy.

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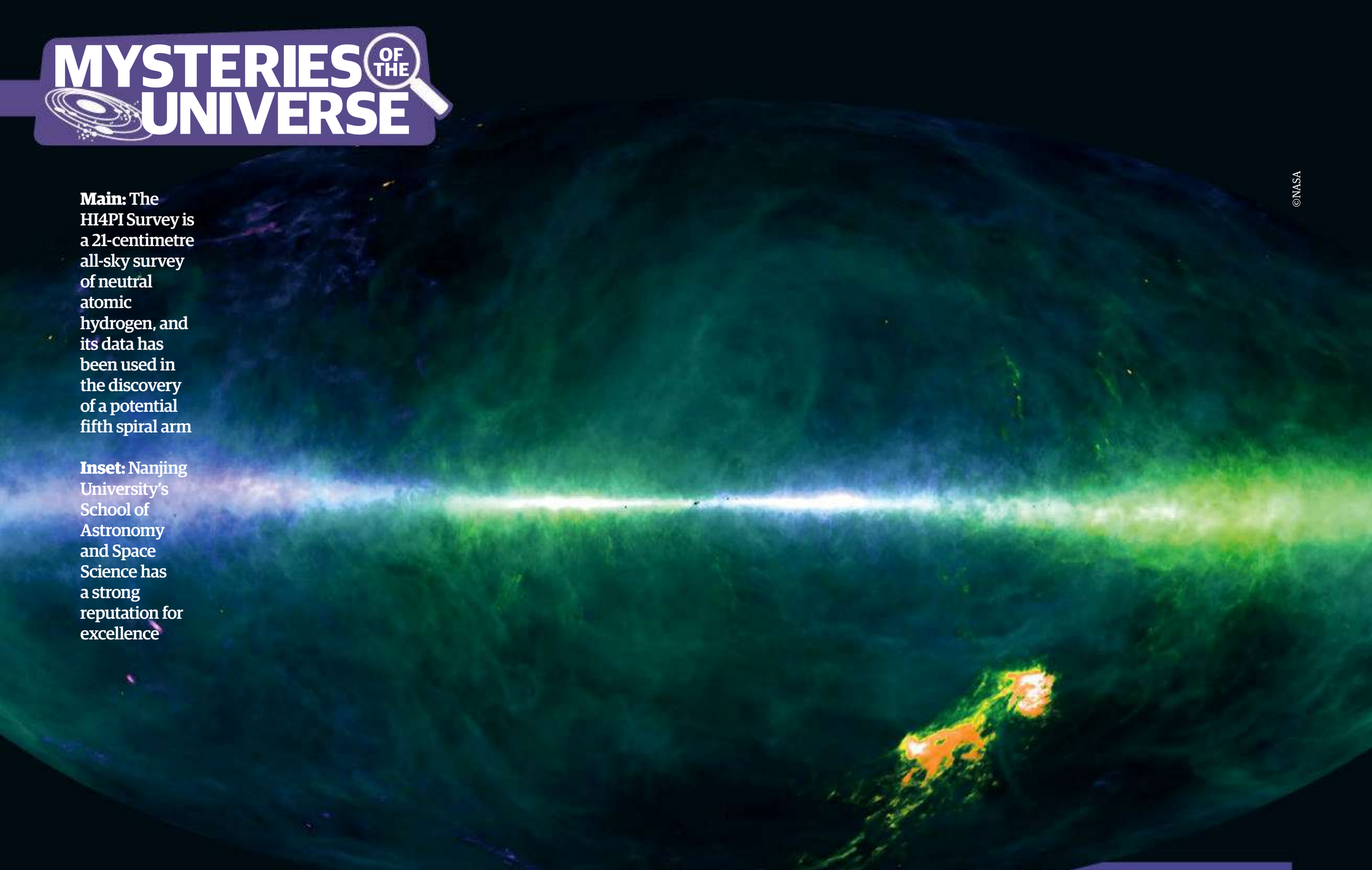

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Main: The HI4PI Survey is a 21-centimetre all-sky survey of neutral atomic hydrogen, and its data has been used in the discovery of a potential fifth spiral arm

Inset: Nanjing University's School of Astronomy and Space Science has a strong reputation for excellence

© Nanjing University

"CATTAIL MIGHT BE PART OF A NEW ARM, THOUGH IT IS PUZZLING THAT THE STRUCTURE DOESN'T FULLY FOLLOW THE WARP OF THE GALACTIC DISC"

KEPING QIU

Observations of atomic and molecular gas with a larger scale are needed to get the nature of Cattail." Indeed, the task now is to determine how Cattail connects with the rest of the galaxy. Does it link with the main portion of the Milky Way, or could it actually be a branch of an existing, known arm? Scientists know that it's part of the galaxy because of its motion, but if it's an entirely new arm then why doesn't it fully follow the wobbly and warped pattern of the galactic disc? It appears to have a different shape to the four known arms, which is why the researchers aren't saying for sure that it is a spiral arm.

"The question about how such a huge filament is produced at the extreme galactic location remains open," says Keping Qiu, who worked with Li on the study. "Cattail might be part of a new arm, though it is puzzling that the structure doesn't fully follow the warp of the galactic disc."

Li agrees with his colleague: "The Milky Way looks like a disc in general," he explains. "The radius of the gas disc is about 98,000 light years, and it warps about 3,260 to 16,300 light years in the outer disc. However, Cattail doesn't fully follow the galactic warp, given that the southwest end is about 5,870 light years away from the warped galactic disc midplane."

These are the sorts of issues that are buzzing around the minds of astronomers – not only in China, but across the world. Anyone who works on finding out more will be looking at how it could have formed, given it's so far away from the centre of the galaxy. For this, there's no clear explanation, particularly if it's only a filament of gas, as the astronomers suspect. But that's why these mysteries are so intriguing, opening up a whole new branch of research.

"Cattail provides new insights into our understanding of the galactic structure," says Li. "As the FAST large-scale neutral atomic hydrogen survey is going, there may be more structures in the extreme outer galaxy that come to light, which will help us to reveal the properties of gas at the edge of our galaxy."

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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The mission will target at least seven main asteroid belt targets

UNITED ARAB EMIRATES TO LAUNCH ASTEROID MISSION IN 2028

After the success of Hope, a new craft will explore targets in the asteroid belt

Reported by Mike Wall

The United Arab Emirates (UAE) has set its sights beyond Mars. The nation has announced plans to launch an ambitious mission to the asteroid belt in 2028. This will be the UAE's second interplanetary effort. The first, the Emirates Mars Mission, launched an orbiter called Hope to the Red Planet in July 2020.

Hope is still going strong on Mars, and the planned asteroid mission will build on its successes. "Our goal is clear: to accelerate the development of innovation and knowledge-based enterprises in the Emirates," said Sarah Al Amiri, chair of the UAE Space Agency.

"This can't be done by going steady state; this requires leaps in imagination, in faith, and the pursuit of goals that go beyond prudent or methodical," Al Amiri said.

"When we embarked on the Emirates Mars Mission, we took on a six-year task that was five times more complex than the Earth-observation satellites we were developing. This mission is five times more complex than EMM," she continued.

If all goes according to plan, the asteroid mission – whose name has not yet been revealed – will launch in 2028. It will perform speed-boosting flybys of Venus and Earth in mid-2028 and mid-2029 respectively, and should make it to the main asteroid belt between Mars and Jupiter in 2030. The probe will study seven different asteroids up close over the course of its mission, which will culminate with a landing on a space rock in 2033.

That final step is quite ambitious. Only a handful of missions – NASA's Near-Earth Asteroid Rendezvous (NEAR) Shoemaker and OSIRIS-REx spacecraft, and Japan's Hayabusa and Hayabusa2 probes – have pulled off a soft landing on an asteroid to date.

The UAE will partner with the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder, on the asteroid mission, which is also a key partner on the Hope Mars mission.

The science goals of the ambitious asteroid mission, and details on the instruments it will carry, will be announced in mid-2022. The asteroid mission is part of the UAE's concerted push into deep space, which also includes the planned delivery of a Moon rover called Rashid to the lunar surface in 2022. The nation hopes such efforts will build technological skills in its populace and help grow and diversify its economy, which has long been heavily reliant on oil exportation.

"Today, we are investing in the generations to come," Sheikh Mohammed bin Rashid Al Maktoum, vice president and prime minister of the UAE and ruler of Dubai, one of the seven emirates that constitute the country, said. "With each new advancement we make in space, we create opportunities for young people on Earth."

"WITH EACH NEW ADVANCEMENT WE MAKE IN SPACE, WE CREATE OPPORTUNITIES FOR YOUNG PEOPLE ON EARTH" MOHAMMED BIN RASHID AL MAKTOUM

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ASTROPHYSICS

Why are neutron stars so dense?

It all comes down to how they're built. Matter as we know it is a bit like candy floss – it's very fluffy and sparse. On Earth, the nuclei of atoms are separated by vast gulfs of space filled with electrons. Imagine an atom was large enough that we could hold its nucleus in our hand: if the nucleus was a penny, the electron cloud in the atom around it would be far bigger than a tennis court. Most importantly, protons and neutrons are a thousand times heavier than electrons, so even though the electrons fill most of the space in atoms, it's actually the nuclei that give them most of their weight. This means we can make matter much denser just by squeezing nuclei together.

Neutron stars, being the imploded cores of massive stars, have effectively crushed all their nuclei together into a giant pudding of neutrons, with the occasional proton and electron sprinkled in. With no gaps left between nuclei, the matter can reach densities hundreds of trillions of times greater than anything on Earth. In fact, if you were to squeeze the Earth down to make a neutron star, it would only be 300 metres (984 feet) across.

Dr Matt Caplan, professor in the Department of Physics at Illinois State University

Above: Just a teaspoon of neutron star would weigh around a billion tonnes

© Getty

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ASTROPHYSICS

Why can't physics describe how gravity works at a subatomic scale?

It might be we just don't know yet, because it's mainly an experimental issue. It's really difficult to measure gravity. It's such a small force, just measuring it is tricky because you have to shield it from all other forces, such as magnetic and electrostatic, that are so much stronger. If you imagine a paperclip, the whole Earth is pulling on it, but just a little magnet is able to pull it up against the gravity of Earth – that's how much stronger the other forces are.

We know how gravity works. Newton and Einstein were mainly concerned about astrophysics or the movements of the planets on big scales. However, on a smaller scale, quantum theory came along, and it describes the world in a very different way. We are going in the direction of measuring smaller and smaller objects, but when we get to even smaller objects, the position of the object is not defined anymore by quantum physics. The theory of gravity from Newton and Einstein just doesn't account for this type of thing. If you want to describe gravity, you must know the position of the object at all times. For small things, as far as we know through quantum mechanics, this isn't true. So what does the gravitational field look like for small things? We have no idea.

Jeremias Pfaff, PhD student, University of Vienna

EXOPLANETS

Can 'mini' gas giants exist?

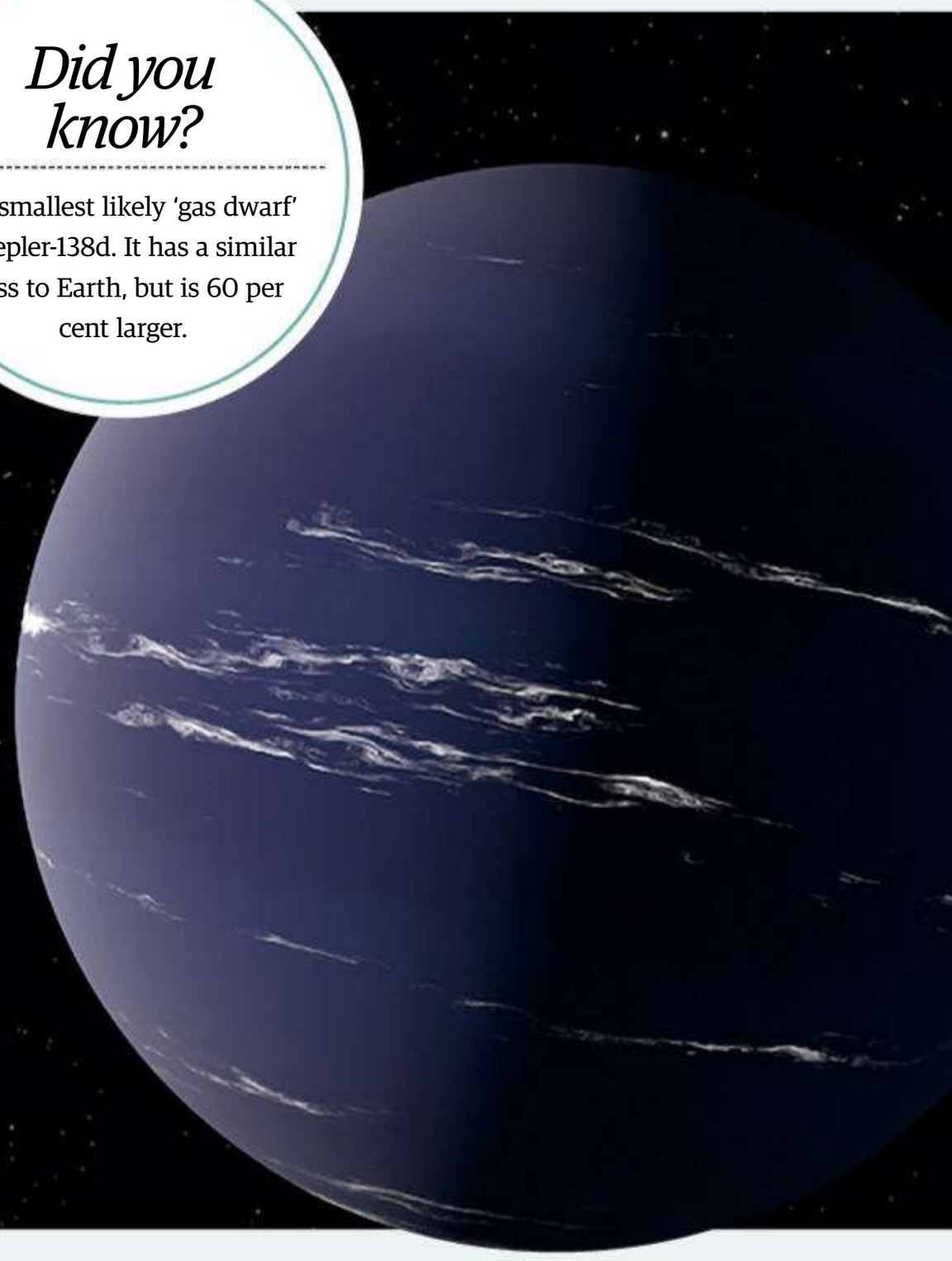
Yes, mini gas giants exist. A gas giant is a planet with most of its atmosphere composed of hydrogen and helium, sitting on top of a solid core that is several times larger than Earth. Within our Solar System, there are four gas giants: Jupiter, Saturn, Uranus and Neptune. However, we have also discovered more than 4,500 planets orbiting other stars.

While some of these 'exoplanets' are the size of our gas giants, a surprising finding is that a significant number of other planetary systems seem to have 'mini' gas giants that are somewhere between Earth and Neptune size, with less gaseous atmospheres – but a lot more than Earth – than our own giant planets. We call them 'mini-Neptunes' or 'sub-Neptunes'. Why is this surprising? Because even though these planets appear to be everywhere, our own Solar System doesn't have a single 'mini' gas giant! We either have gas giants, or we have small, rocky planets. This might be a result of different planet formation processes, and we will know a lot more about the atmospheres of these 'mini gas giants' when NASA launches the James Webb Space Telescope.

Dr Ravi Kopparapu, planetary scientist at NASA's Goddard Space Flight Center

Did you know?

The smallest likely 'gas dwarf' is Kepler-138d. It has a similar mass to Earth, but is 60 per cent larger.



Above: All objects with mass have some gravitational pull

Right: Neptune is the Solar System's smallest gas planet, but is still quite large

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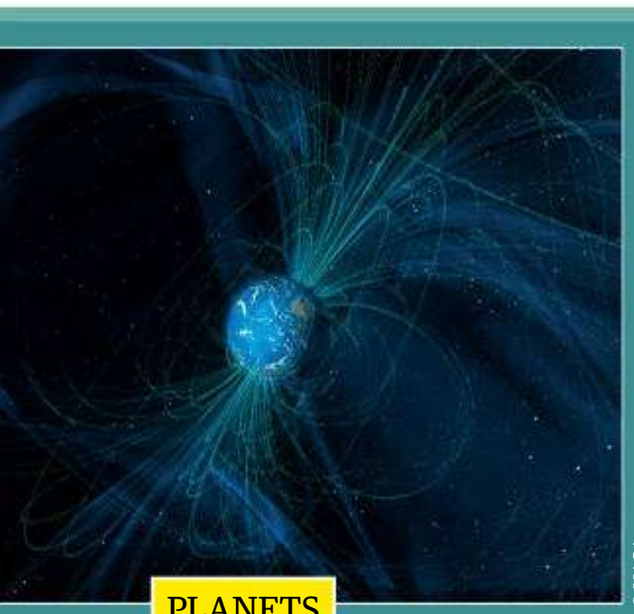
Our experts answer your questions



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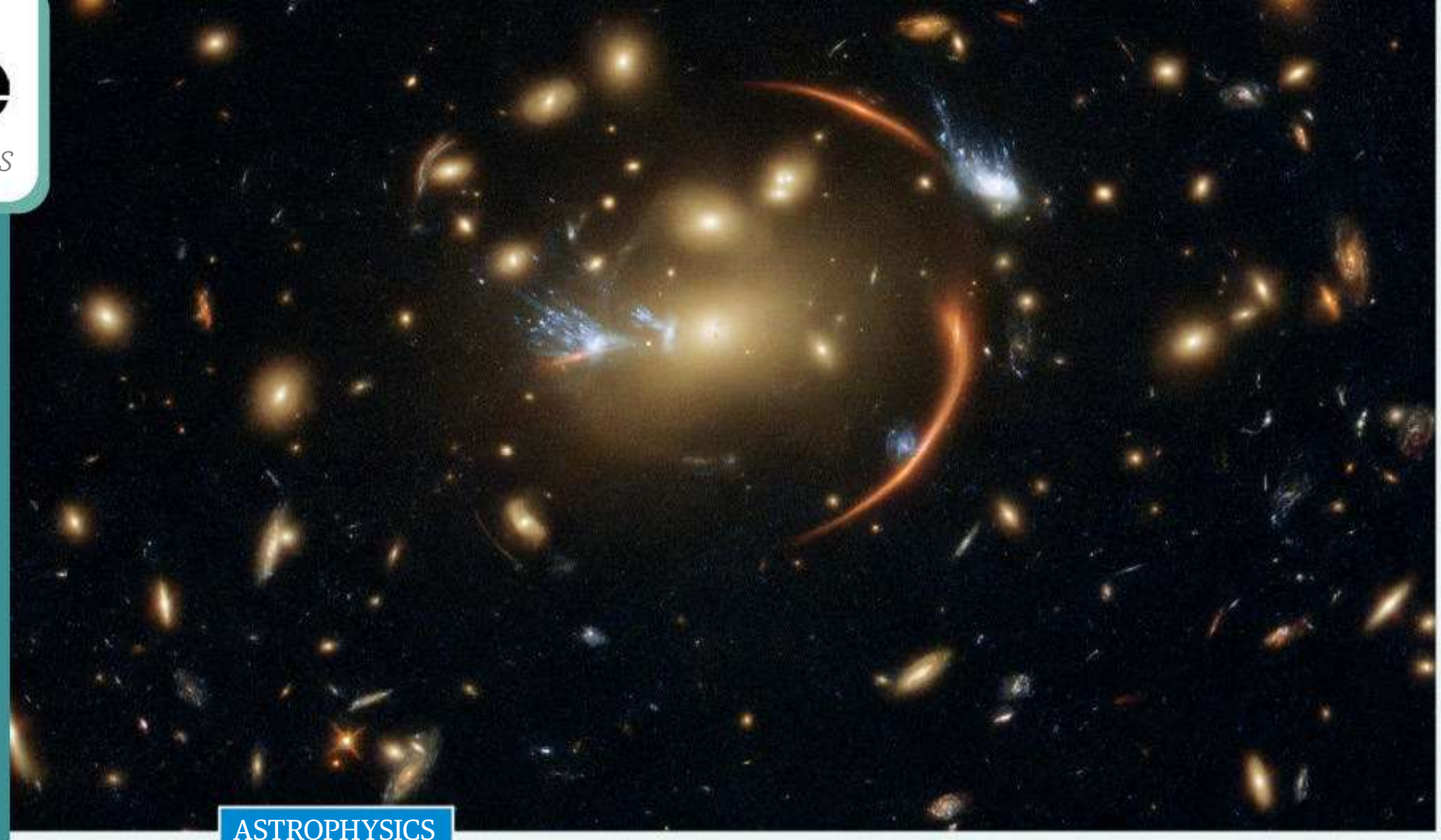
PLANETS

Do all planets have a magnetic field?

Most planets do. Of the main planets in our Solar System, only Venus and Mars lack global magnetic fields. Mars has crustal magnetic fields in its ancient southern hemisphere. This is evidence for an early global Martian magnetic field, which stopped 3.8 billion years ago, a time when life may have developed – we hope to find out with the Rosalind Franklin rover in 2023. The solar wind has stripped the Mars atmosphere; now it has only one per cent of Earth's atmospheric pressure. The planetary magnetic fields are all different. Earth's north magnetic pole is currently in the Southern Hemisphere, and it's due to 'flip' in the next few thousand years. We don't understand why Mercury has a magnetic field at all – BepiColombo will find out in 2025. If you could see Jupiter's magnetic field, it would be many times the size of the Moon; Saturn's field is not as large. Uranus and Neptune's fields are at large angles from their rotation axes. Ganymede has a unique magnetic field – a magnetosphere within Jupiter's huge magnetosphere – and this will be visited by the ESA's JUICE mission in the 2030s.

Andrew Coates, professor of physics at University College London



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ASTROPHYSICS

What is a gravitational lens?

A gravitational lens is a distortion of space that bends light from objects behind it. Anything with mass – the Earth, the Sun, black holes, you – pulls at space around it. Another object with mass feels that distortion, and as a result, both tend to fall towards one another. We call this force gravity.

Light does not have mass. But light travelling through the distorted space slows down. This is exactly what happens when light passes through glass. Just like a glass lens is thicker in the middle and thinnest at the rim, space is most distorted nearest the mass and less so further out. Gravitational distortions of space therefore act like lenses do – they magnify sources behind it. This can happen when a star passes at some distance behind another, or when a distant galaxy is seen behind a galaxy in the foreground. Like with a telescope, it allows us to see things that otherwise would be too dim. The magnified images look stretched out, though. While this may look weird, it makes them easy to find. Lensed galaxies are then powerful tracers of the mass that makes up the lens. This is one way in which to map dark matter, which doesn't give off light at all.

Dr Jacco van Loon, director of Keele Observatory, Keele University

SOLAR SYSTEM

What can volcanoes tell us about other planets?

Volcanoes tell us how planets get their heat out and what they are made of. If volcanoes are erupting today, we can measure the rate of heat escape and compare it with the rate at which we expect heat to be produced inside by radioactive decay. The more than 100 currently erupting volcanoes on Jupiter's volcanically active moon Io can't be driven by radioactivity alone, showing that Io is heated by tidal deformation. We'd love to know for sure whether Venus' volcanoes are active today or are relics from the planet's past. Either way, their distribution doesn't conform to the type of pattern we see on Earth, where volcanoes occur mostly close to boundaries between tectonic plates, so Earth and its 'twin' do not bear all that close a resemblance.

Ancient volcanoes are informative too. The sheer size of Olympus Mons on Mars, rising 22 kilometres (13.6 miles) above its base, tells us that the planet's outer shell is thick and strong, and has remained stationary above the magma source for over a billion years. On Mercury we have found volcanic vents where eruptions in the past billion years have been explosive. This can happen only when there is something available to be liberated from the magma violently in the form of gas when it approaches the surface, which is surprising in a planet so close to the Sun.

© NASA

David Rothery, professor of planetary geosciences at the Open University

Did you know?

The term hycean is a portmanteau of the words hydrogen and ocean.

EXOPLANETS

What is a hycean planet?

Above: Simple aquatic life could arise on hycean worlds

Hycean planets are a class of planets bigger than Earth and smaller than Neptune with massive, planet-wide oceans and atmospheres made mostly of hydrogen. Astronomers have discovered thousands of exoplanets. The most common types of exoplanets discovered so far are unlike any planet in the Solar System, and are between the sizes of Earth and Neptune. It is not yet known what the interiors of these planets are made of, but one theory is that some of them could be rich in water, with massive oceans covering the surface. If such a planet is at the right temperature, the ocean could even be habitable for some types of life, for example certain microbes.

Hycean planets are defined as having planet-wide oceans at temperatures which are habitable for some types of life. They also have puffy, hydrogen-rich atmospheres and can be up to 2.6 times larger than the Earth, with atmospheric temperatures up to 200 degrees Celsius (392 degrees Fahrenheit). While there isn't yet enough data to unambiguously identify a hycean planet, several known exoplanets have been classed as potential hycean candidates based on their sizes, temperatures and parent stars. Observations with large telescopes in the near future will help to determine if these planets are indeed hycean, and whether any of them could be harbouring life.

© Gertty

Anjali Piette, PhD student, University of Cambridge

BEGINNER'S GUIDE TO STARGAZING WITH BINOCULARS

GET A NEW PERSPECTIVE OF THE JEWELS OF THE NIGHT SKY BY OBSERVING WITH BINOCULARS

Written by Jamie Carter and Russ Swan

Are you ready to go deeper into the night sky? If you're done figuring out the constellations and now want to probe the star clusters, nebulae and planets hidden within them, there's no better investment than a decent pair of binoculars.

Capable of giving you a close up of deep-sky objects that are invisible to your naked eye and often impossible to appreciate through even the best telescopes, stargazing with binoculars can be inexpensive, but always expansive, instantly unlocking a new layer to your view of the vast beyond. Here are some top tips for getting the most out of the best binoculars for stargazing and astronomy and seeing hundreds of thousands of stars, star clusters and galaxies.

If you think a telescope is better for astronomy than stargazing with binoculars, then you're misunderstanding the nature of the night sky. It's in three dimensions: it's got depth and objects of vastly different sizes. While a telescope's magnification is useful for looking at deep-sky objects with a small apparent size close up, their restricted field of view means they're not as good for studying closer objects or those with a larger apparent size. There are three other reasons why stargazing with binoculars trumps a telescope: they're much more affordable, ridiculously easy to use and show a right-side-up image, unlike many telescopes which show everything upside down.

Some objects that look uniquely beautiful when stargazing with binoculars include the Orion Nebula (M42), the Andromeda Galaxy (M31), the Pleiades (M45) and Hyades open clusters in the constellation of Taurus, the binary pair Mizar and Alcor in the Big Dipper and, of course, the Moon. You can also point your binoculars at Jupiter to see not only the gas giant itself in all its glory, but its four giant Galilean moons: Ganymede, Europa, Callisto and Io.

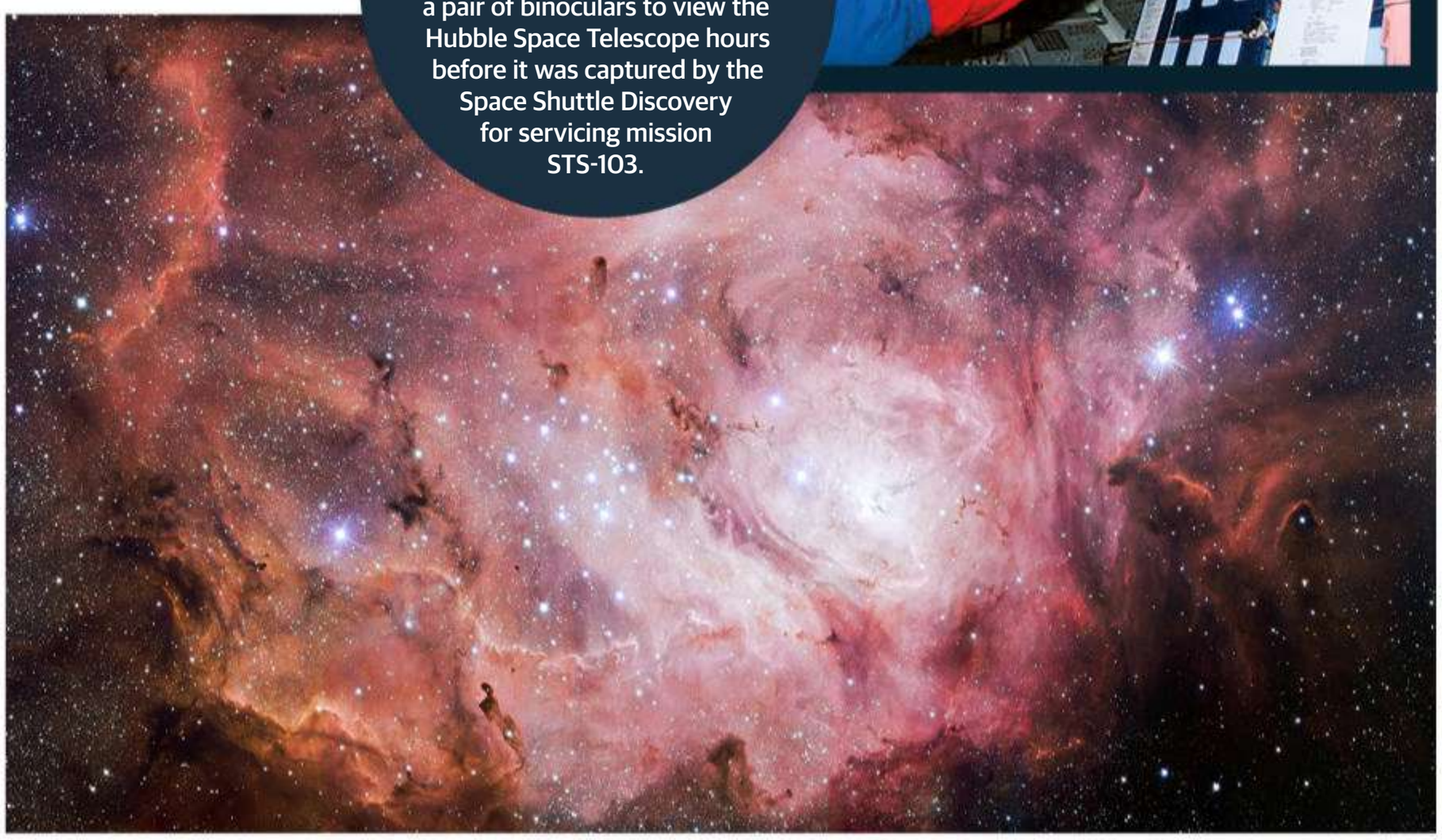
A great way to approach binocular stargazing is to use them to help you discover what's in that 'second layer' of the night sky as you learn to navigate the cosmos by tracing out the bright stars. Sweep your binoculars across constellations close to the Milky Way, such as Cassiopeia and Perseus in winter and through the Summer Triangle asterism in summer, and you'll be astounded by what you can see.

© NASA

Below: Binoculars can also be used to peek out of spacecraft windows

DID YOU KNOW?

Binoculars also come in handy during spaceflight. In this image, astronaut John M. Grunsfield uses a pair of binoculars to view the Hubble Space Telescope hours before it was captured by the Space Shuttle Discovery for servicing mission STS-103.



© ESO

HOW TO...

FOCUS YOUR BINOCULARS

There's more to stargazing with binoculars than using that focusing knob on the top. Many binoculars also have a diopter ring around the right eyepiece that helps you compensate for differences between your eyes. To calibrate, in daylight put a lens cap over the right barrel and use the central focusing knob to create a sharp image for your left eye for something in the middle distance. Then put a lens cap on the left barrel and use the diopter ring to focus for your right eye.

HOLD YOUR BINOCULARS STEADY

Does everything look wiggly? That's because you're moving constantly. If you're looking straight ahead at something close to the horizon, you're also battling gravity. When stargazing with binoculars, hold them near the end of the tubes, not close to the eyepiece, keep your elbows in against your chest and either lean against a wall or sit in a chair. If you look directly up and let the binoculars rest on your face, you'll no longer be fighting gravity, so should get a more stable image.

FIND OBJECTS WITH YOUR BINOCULARS

Get yourself a star chart, and maybe a mobile astronomy app for your phone, and decide what you're going to look at. Even if it's something bright, like Jupiter or the Moon, it's likely that you'll have a little trouble aiming the first time you're stargazing with binoculars. The best way to aim is to find the location of the object you want to see with your naked eye and then put the binoculars in front of your eyes. If you need to scan the area, do so in a circular movement.

USE AVERTED VISION

Point your binoculars at something with diffuse light – the Andromeda Galaxy (M31) or the Great Globular Cluster in Hercules (M13) – and you might not get the full impact. That's because you're looking straight at them. Your peripheral vision is most sensitive to brightness, so look slightly to the side of a faint, fuzzy object and your eyes will see a lot more light. This averted vision technique is as close to a long-exposure photograph as the human eye can get.

Binocular stargazing

The first thing that beginners look at through their new binoculars is almost always the Moon. Binoculars are perfect for following the Moon's phases as it orbits Earth each month. A couple of evenings after the new Moon, you'll be able to see a crescent Moon in the western sky just after sunset. The slim curve of light looks incredible through binoculars, but look to the darkened limb and you'll see 'earthshine' – reflected light from the Earth shining back onto the Moon.

As the month wears on, point your binoculars at the terminator, the line between light and dark on the Moon, and you'll see shadows that reveal vast craters – Copernicus, Tycho and Plato, to name a few – mountain ranges such as the Montes Apenninus and lunar seas such as the Sea of Tranquillity, Sea of Showers and Ocean of Storms. The Moon looks flat when it's full, and almost too bright to look at through binoculars, so catch it at moonrise around dusk and you'll get a wonderful view of our natural satellite in space.

There's a tendency for those new to stargazing to hear the words 'meteor shower' and fetch their telescope or binoculars. While binoculars are excellent for stargazing, they're not ideal for all-sky celestial events. That includes meteor showers, for which you need as wide-eyed a view of the night sky as possible. The same goes for aurorae, which always look best when viewed with the naked eye.

You should also avoid using a pair of binoculars for any kind of planet spotting or stargazing close to the Sun if it's in the sky. That includes solar eclipses – though it is safe to use binoculars to look at the Sun's corona during the brief moments of totality. In fact, there's not many more beautiful sights in nature than the Sun's corona through binoculars. Used wisely, a simple pair of binoculars can bring a lifetime of joy from stargazing without you ever having to go near a cumbersome, complicated telescope.

The best binoculars for stargazing balance magnification with letting as much light in as possible. For beginner stargazers, the ideal combination is a low magnification of around 7x to 10x and an aperture of about 42mm to 50mm. Binoculars with these specifications – expressed as 7x42, 10x50 or similar combinations – are small and light enough to hold reasonably steady. They also give a wide enough field of view of the night sky and create a bright image in darkness. Our favourite pair are the Celestron TrailSeeker 8x42 binoculars.

If you wear glasses, it's also worth thinking about the distance that your eyes are from the eyepiece. This eye relief can make all the difference to comfort when stargazing with binoculars, and if you wear glasses you'll benefit from a longer eye relief. Other technical features to look out for are Porro prisms, multi-coated optics and barium crown (BAK-4) glass. All should feature in stargazing-centric binoculars.

Learning how to clean your binoculars is paramount if you want to keep them in good shape. Whether you've bought a pair from the bargain bin or splurged an astronomical amount on some of the best binoculars around, you've made an investment worth protecting. That starts with keeping them – and especially their lens surfaces – clean.

The first step may seem obvious: try not to get them dirty in the first place. Lens caps can be fiddly, but they will protect your optics during transport and set-up. We don't know why manufacturers nearly always colour their lens caps black, as this makes them especially easy to lose in the dark. When handling binoculars, avoid touching the lenses with your fingers. This will inevitably leave an oily smudge to spoil your view of the heavens. You may be tempted to simply polish this away, but be careful. Never use any kind of paper – not even soft tissue – on optical surfaces. Paper is surprisingly abrasive, and could damage the lens coatings.

Binocular and telescope lenses are coated with layers of chemicals to increase their transmission of light, reduce reflections and cut out aberrations that create coloured fringes around bright objects. Modern coatings are pretty tough, but are still vulnerable to damage. Remember, they are the only thing between the outside world and the expensive precision glass inside. Damage the coating and you have damaged the lens, and therefore the binoculars.

Use a clean, soft, dry cloth, ideally a microfibre cloth, which should not leave any traces of lint behind. If you see any dust or grit, remove this first, and then wipe the cloth carefully over the lenses. We recommend using a circular motion rather than up and down, because any tiny impressions left behind will be less likely to impair lens performance. Lens cleaning fluids or impregnated wipes can be useful, and should evaporate without leaving a residue. If you're unsure, try using it on a window or drinking glass to see how effective

TOP TIPS FOR BUYING BINOCULARS FOR KIDS

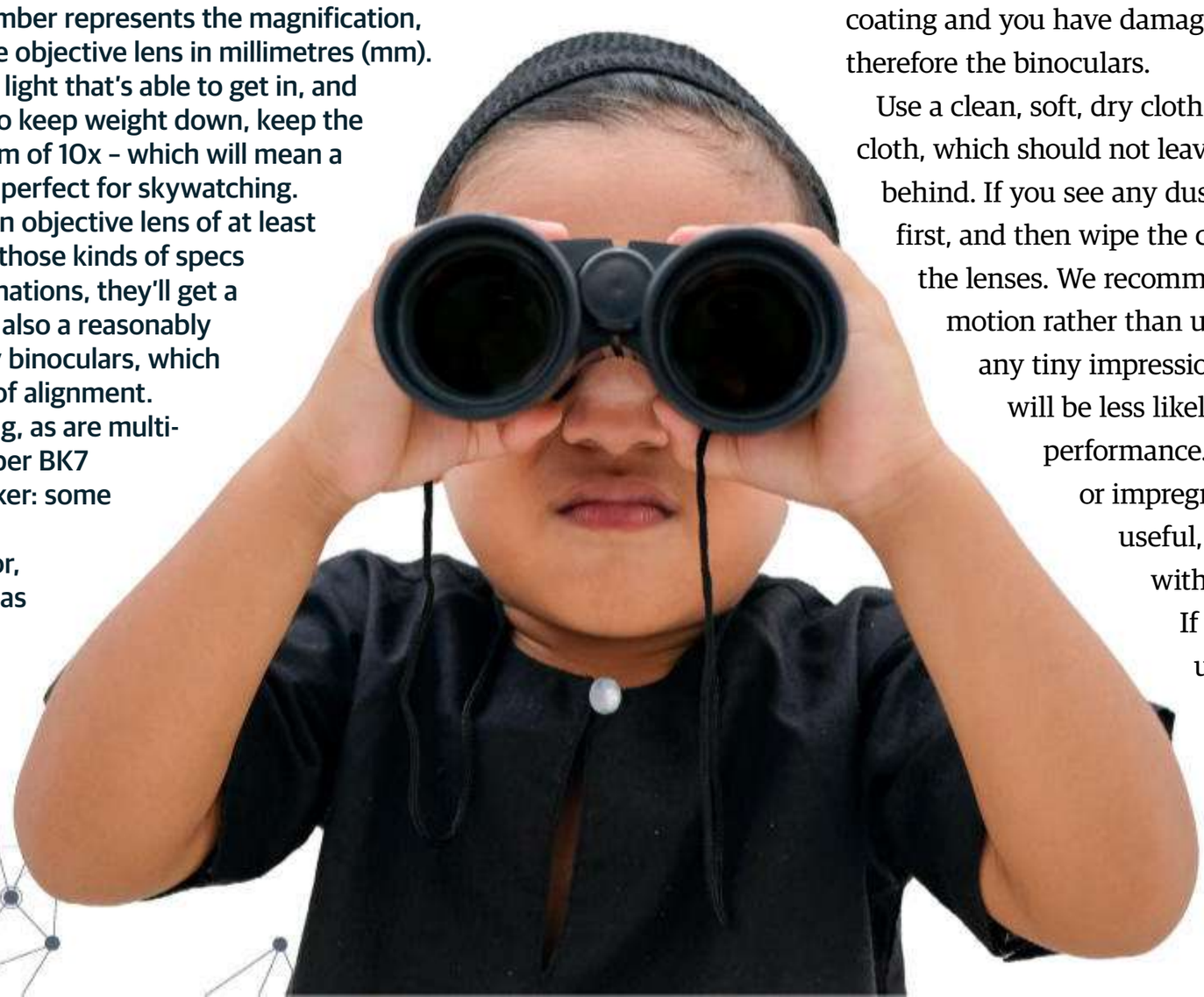
Should you buy binoculars for a child looking to get into astronomy? Yes! Most parents go straight for a cheap telescope the moment a child asks about the stars or the Moon, yet almost all of them soon collect dust, not light. Cue a pair of binoculars, which are much simpler to use and perfect for giving children their first close-up views of the lunar surface, planets, star clusters and even galaxies.

Binoculars are ideal for beginners and young astronomers because they're easy to carry and take on trips, but there are a few things to bear in mind when choosing the best binoculars for kids. Don't just consider small binoculars, which limit the light that gets to their eyes and ultimately reduces what they'll see – especially at night.

When shopping around for binoculars, you'll notice a selection of numbers: 6x21, 7x30, 10x50 and so on. The first number represents the magnification, while the second gives the diameter of the objective lens in millimetres (mm). The higher that second number, the more light that's able to get in, and the better the view of night-sky targets. To keep weight down, keep the magnification low – about 7x to a maximum of 10x – which will mean a wider and more stable field of view that's perfect for skywatching.

To let enough light in at night, choose an objective lens of at least 30mm, but ideally 42mm or 50mm. With those kinds of specs together as 7x42, 10x50 and other combinations, they'll get a bright wide-field view of the heavens and also a reasonably stable image. You should avoid buying toy binoculars, which use poor-quality lenses and easily go out of alignment. Porro prisms are preferred for skywatching, as are multi-coated optics and BAK-4, but use of cheaper BK7 glass shouldn't be considered a deal-breaker: some perform well for those on a budget.

Just remember that whatever you go for, binoculars in the hands of a child are only as good as how steady they hold them. Get them to hold the binoculars towards the end of the tubes, not close to their eyes, and keep their elbows in. Better still, get them to lean against a wall or sit in a lawn chair.



BEST OBJECTS TO VIEW TONIGHT

© NASA, ESA

THE ORION NEBULA (MESSIER 42)

Where to find it:
Orion

This emission-reflection nebula is one of the brightest nebulae in the sky, and can even be visible to the naked eye under dark skies with no light pollution or bright moonlight. You can find the nebula halfway down Orion's sword, appearing as a hazy-looking star.

© ESA/ESO/NASA

THE PLEIADES (MESSIER 45)

Where to find it:
Taurus

Also known as the 'Seven Sisters', this open star closer consists of more than 800 stars. To find the Pleiades, follow the three stars in Orion's Belt and follow them upwards past his bow. The first bright star is Aldebaran, and the cluster is located a little further along.

© ESA/Hubble

ANDROMEDA GALAXY (MESSIER 31)

Where to find it:
Andromeda

Located a 'mere' 2.5 million light years away is the nearest large spiral galaxy to the Milky Way. Andromeda can be spotted by first finding the constellation of Cassiopeia. Locate its brightest star, Schedar, which will appear to point to the Andromeda Galaxy.

© NASA, ESA & Hubble

GREAT GLOBULAR CLUSTER (MESSIER 13)

Where to find it:
Hercules

This globular star cluster contains over 100,000 stars and is one of the brightest star clusters visible in the Northern Hemisphere, making it a favourite object of many. M13 can be found in the constellation Hercules between two bright stars, Vega and Arcturus.

© ESA/ESO/NASA

THE ROSETTE NEBULA (NGC 2237)

Where to find it:
Monoceros

Named for its shape, this beautiful emission nebula is about 130 light years across. To find this target in the night sky, first look to the left of Orion, the Hunter. You can find the Rosette Nebula high in the sky and close to the bright star Betelgeuse, a red supergiant.

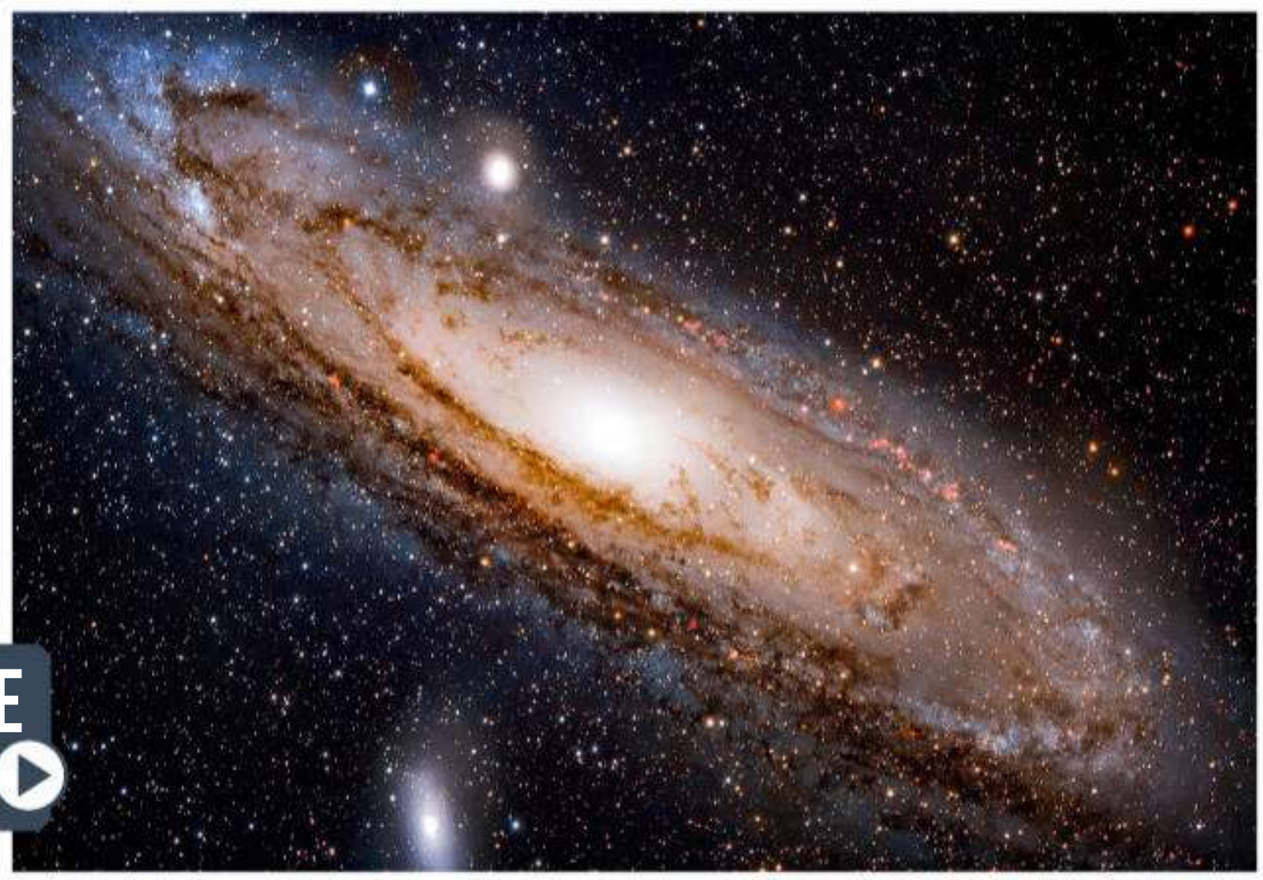
it is before applying it to your precious binoculars. Never, ever use domestic window cleaning products, though.

Dirt, grit and dust are your worst enemies when caring for binoculars and good-quality telescopes, as they can easily scratch delicate optical surfaces – and this is most likely to happen when cleaning is performed. The trick is to get rid of dust and grit without pressing it into the lens, which could cause scratches. The best way is by suction, but unless you happen to have a vacuum cleaner to hand, this is probably impractical. A more useful approach is to use a puffer brush, consisting of a small rubber balloon with a soft brush attached. These are inexpensive and widely available from camera shops and online.

Holding the binoculars up so that the offending material can fall away, deliver a few puffs from a close distance. Follow with a couple of circular sweeps with the brush – puffing at the same time if necessary – and you will almost certainly have shifted any dry dust or dirt. If you can't get hold of a puffer, a soft-bristle brush is the next best thing. A clean paintbrush or a makeup brush can be used – the softer the better, but do make sure it's absolutely clean, and preferably unused, or you might just make the problem worse. Do you have a little sachet of moisture absorber, probably silica gel, in your binocular case? If so, keep it there; it's doing a valuable job. While you're out observing the skies, your binoculars will cool down. When you bring them back into the house, condensation can form on the cold surfaces, including the lenses.

This moisture will practically glue any passing mote of dust to your binoculars, and can also encourage fungal growth. That's why it's a good idea to dry your binoculars before storing them. First allow them to come to room temperature, then wipe them down with a soft, dry cloth, taking extra care with the optical surfaces. Store them in their case with the absorbent. Silica gel can only absorb a certain amount of moisture, but can be recharged by drying it in a low oven for an hour or two. Following these few simple steps will preserve the life and maintain the performance of your valuable optical investment.

Right: Some binoculars will show nearby galaxies as smudges of light when used under a dark sky



Source: Wikipedia Commons © David (Deddy) Dayag

TAP HERE TO PLAY

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STARGAZER

WHAT'S IN THE SKY?

IN THIS ISSUE...

78 What's in the sky?
The darker November skies can provide hours of observing enjoyment

82 Month's planets
Mercury takes pride of place in the dawn sky from November, but take care observing it

84 Moon tour
Find a huge impact basin on the Moon, even without a telescope

85 Naked eye and binocular targets
Glittering stars and spectacular star clusters

86 Deep sky challenge
Track down some of winter's lesser known wonders on the next clear and chilly night

88 The Northern Hemisphere
The autumn constellations fade into winter's

90 Astroshots of the month
The best of our readers' astrophotography

92 App review
We put the Starlight astronomy app to the test

96 In the shops
Our pick of the best products for astronomy and space fans

"AN OBJECT'S MAGNITUDE TELLS YOU HOW BRIGHT IT APPEARS FROM EARTH. MAGNITUDES ARE REPRESENTED ON A NUMBERED SCALE"

RED-LIGHT FRIENDLY
In order to preserve your night vision, you should read our observing guide under red light

7 NOV
Comet 67P/Churyumov-Gerasimenko will reach its predicted brightness of +8.3 in Gemini

10 NOV
The Moon and Saturn make a close approach, within 4°00' of each other in Capricornus

10 NOV
Conjunction between the Moon and Saturn in Capricornus

© ESA

11 NOV
Conjunction between the Moon and Jupiter in Capricornus

17 NOV
The Leonid meteor shower reaches its peak

21 NOV
The Alpha Monocerotid meteor shower reaches its peak

27 NOV
Dwarf planet Ceres reaches opposition in Taurus, glowing at magnitude +7.2

© NASA

JARGON BUSTER

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

©Alamy

11 NOV
The Moon and Jupiter make a close approach, within 4°08' of each other in Capricornus

12 NOV
The Northern Taurid meteor shower reaches its peak

13 NOV
Comet 67P will make its closest approach to the Sun in Cancer, glowing at +8.3

17 NOV
The Pleiades star cluster (Messier 45) is well placed in Taurus, glowing at +1.3

19 NOV
Partial lunar eclipse visible from Oceania, the Americas, Eastern Asia, Northern Europe

©NASA, ESA

28 NOV
The November Orionid meteor shower reaches its peak

1 DEC
Neptune ends its retrograde – or backwards – motion in the night sky

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

15 DECEMBER 2021

OPPOSITION

EVENING SKY

MOON CALENDAR

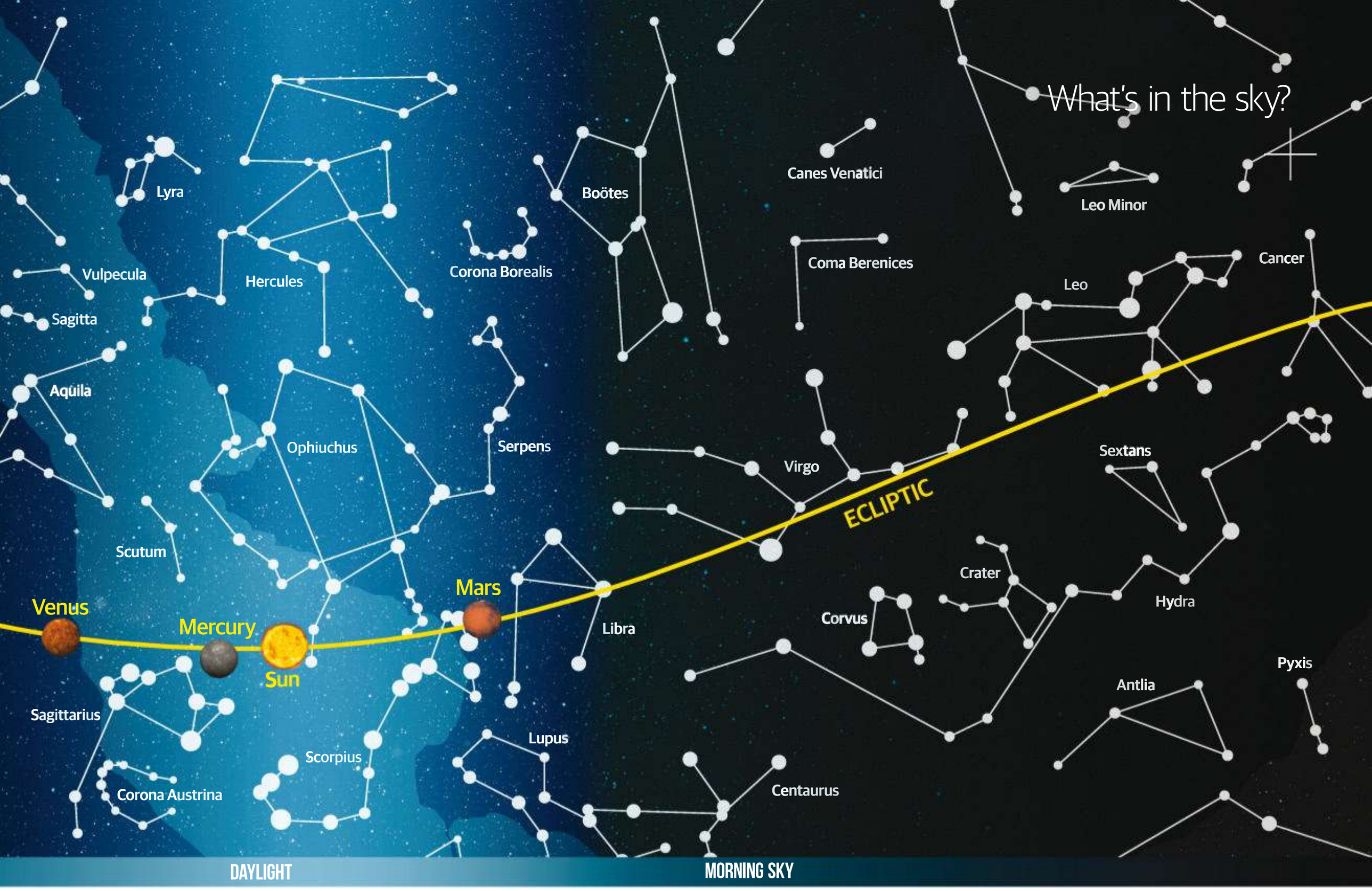
* The Moon does not pass the meridian on 19 November

4 NOV NM 0.3% 06:06 16:27	5 NOV 0.6% 07:37 16:50	6 NOV 4.2% 09:10 17:21	7 NOV 10.7% 10:38 18:03			
8 NOV 19.6% 11:53 19:01	9 NOV 30.1% 12:51 20:12	10 NOV 41.3% 13:32 21:32	11 NOV FQ 52.7% 14:01 22:53	12 NOV 63.5% 14:22 --:--	13 NOV 73.4% 00:12 14:39	14 NOV 82.0% 01:28 14:53
15 NOV 89.1% 02:41 15:06	16 NOV 94.6% 03:52 15:19	17 NOV 98.2% 05:02 15:33	18 NOV 99.9% 06:13 15:50	19 NOV FM --:--%* 07:24 16:09	20 NOV 99.6% 08:34 16:35	21 NOV 97.5% 09:41 17:08
22 NOV 93.6% 10:41 17:51	23 NOV 88.1% 11:32 18:45	24 NOV 81.0% 12:12 19:48	25 NOV 72.6% 12:43 20:59	26 NOV 63.1% 13:07 22:13	27 NOV TQ 52.9% 13:26 23:29	28 NOV 42.2% 13:42 --:--
29 NOV 31.5% 00:47 13:57	30 NOV 21.3% 02:08 14:12	1 DEC 12.4% 03:31 14:29	2 DEC 5.4% 04:59 14:49			

% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE

PLANET POSITIONS

All rise and set times are given in GMT

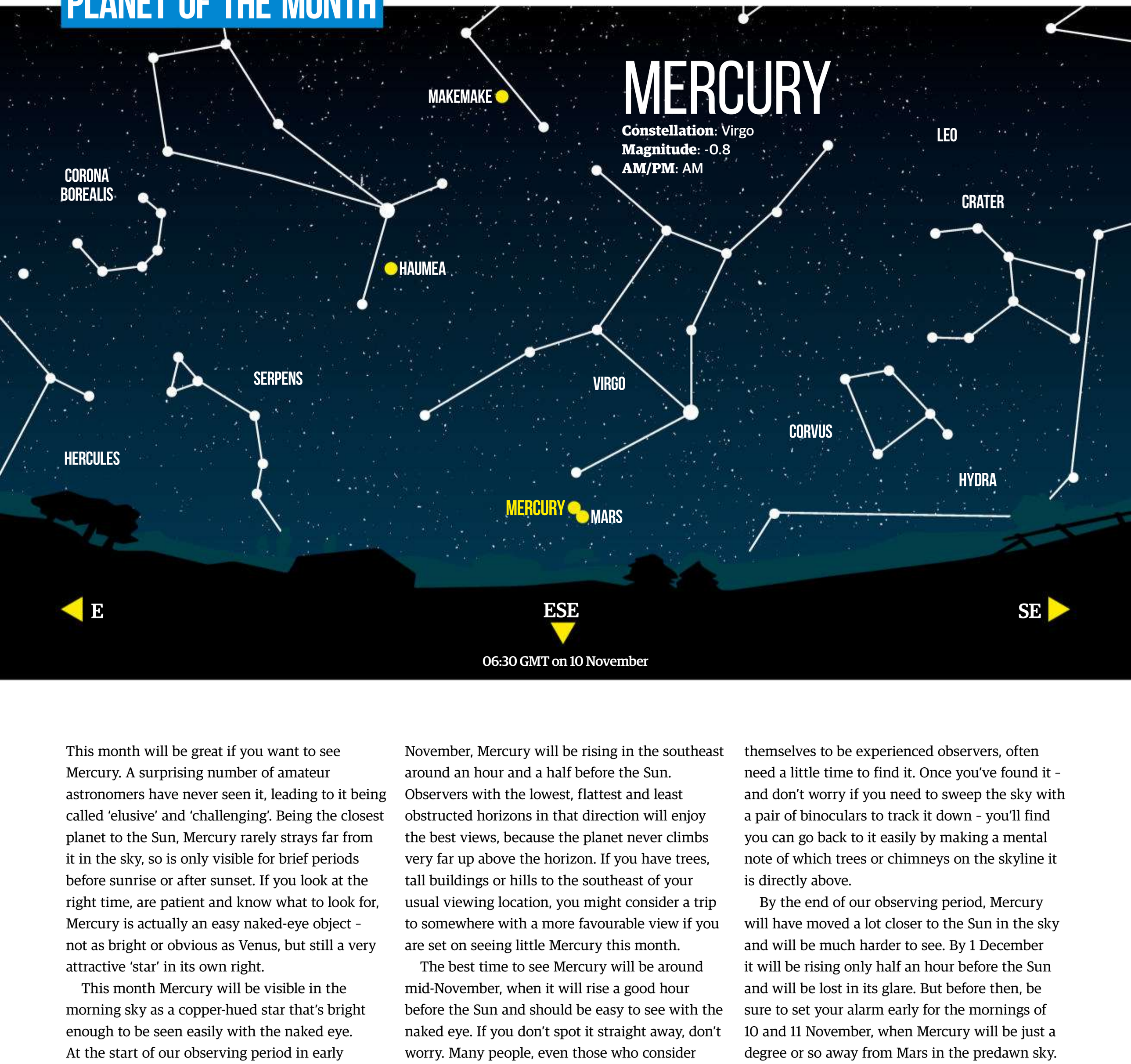
DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
4 NOV	13h 41m 40s	-08° 29' 18"	Virgo	-0.9	06:30	17:02
11 NOV	14h 23m 33s	-12° 53' 14"	Libra	-0.9	07:08	16:52
18 NOV	15h 07m 12s	-16° 59' 22"	Libra	-1.0	07:47	16:45
25 NOV	15h 52m 04s	-20° 27' 41"	Libra	-1.3	08:26	16:41
3 DEC	16h 44m 59s	-23° 25' 30"	Libra	-1.2	09:02	16:41
4 NOV	17h 52m 25s	-27° 12' 09"	Sagittarius	-4.5	12:37	19:14
11 NOV	18h 21m 45s	-27° 09' 48"	Sagittarius	-4.5	12:39	19:16
18 NOV	18h 48m 41s	-26° 40' 49"	Sagittarius	-4.6	12:34	19:20
25 NOV	19h 12m 20s	-25° 48' 59"	Sagittarius	-4.6	12:23	19:23
3 DEC	19h 34m 02s	-24° 28' 06"	Sagittarius	-4.7	12:06	19:23
4 NOV	14h 02m 26s	-11° 59' 05"	Virgo	+1.7	07:09	17:04
11 NOV	14h 20m 39s	-13° 37' 20"	Virgo	+1.6	07:09	16:45
18 NOV	14h 39m 13s	-15° 11' 03"	Libra	+1.6	07:09	16:27
25 NOV	14h 58m 11s	-16° 39' 29"	Libra	+1.6	07:09	16:10
3 DEC	15h 20m 22s	-18° 13' 07"	Libra	+1.6	07:09	15:54
4 NOV	21h 40m 53s	-15° 03' 38"	Capricornus	-2.5	15:03	00:24
11 NOV	21h 42m 41s	-14° 53' 33"	Capricornus	-2.5	14:37	23:59
18 NOV	21h 45m 04s	-14° 40' 30"	Capricornus	-2.4	14:10	23:35
25 NOV	21h 47m 59s	-14° 24' 35"	Capricornus	-2.4	13:44	23:12
3 DEC	21h 51m 56s	-14° 03' 07"	Capricornus	-2.3	13:18	22:50
4 NOV	20h 38m 41s	-19° 17' 48"	Capricornus	+0.6	14:27	22:56
11 NOV	20h 39m 58s	-19° 12' 56"	Capricornus	+0.6	14:00	22:31
18 NOV	20h 41m 34s	-19° 06' 54"	Capricornus	+0.7	13:33	22:05
25 NOV	20h 43m 27s	-18° 59' 45"	Capricornus	+0.7	13:07	21:40
3 DEC	20h 45m 55s	-18° 50' 15"	Capricornus	+0.7	12:41	21:16

STARGAZER

THIS MONTH'S PLANETS

Mercury takes pride of place in the dawn sky from November, but take care observing it as we head into December

PLANET OF THE MONTH



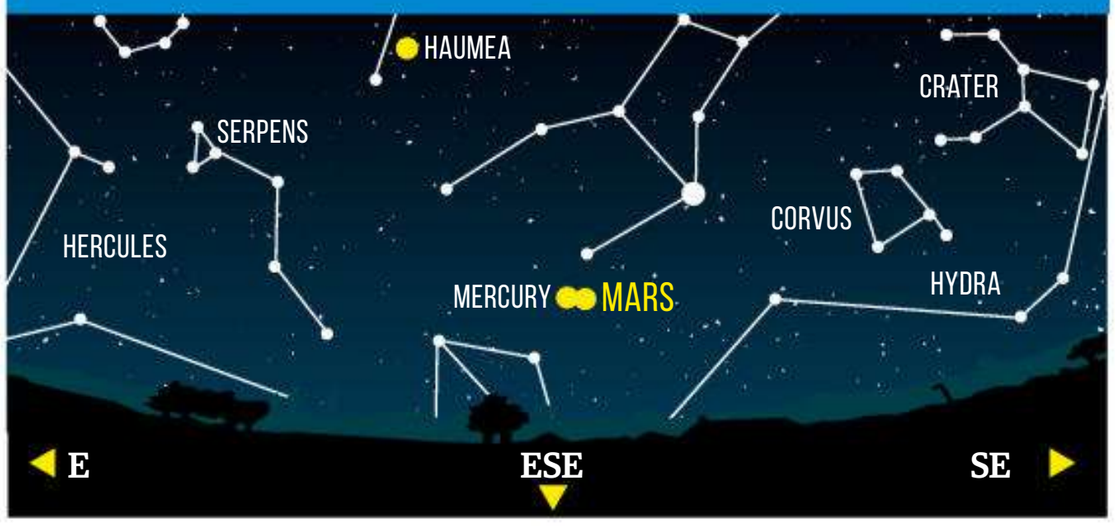
This month will be great if you want to see Mercury. A surprising number of amateur astronomers have never seen it, leading to it being called 'elusive' and 'challenging'. Being the closest planet to the Sun, Mercury rarely strays far from it in the sky, so is only visible for brief periods before sunrise or after sunset. If you look at the right time, are patient and know what to look for, Mercury is actually an easy naked-eye object – not as bright or obvious as Venus, but still a very attractive 'star' in its own right.

This month Mercury will be visible in the morning sky as a copper-hued star that's bright enough to be seen easily with the naked eye. At the start of our observing period in early November, Mercury will be rising in the southeast around an hour and a half before the Sun. Observers with the lowest, flattest and least obstructed horizons in that direction will enjoy the best views, because the planet never climbs very far up above the horizon. If you have trees, tall buildings or hills to the southeast of your usual viewing location, you might consider a trip to somewhere with a more favourable view if you are set on seeing little Mercury this month.

The best time to see Mercury will be around mid-November, when it will rise a good hour before the Sun and should be easy to see with the naked eye. If you don't spot it straight away, don't worry. Many people, even those who consider themselves to be experienced observers, often need a little time to find it. Once you've found it – and don't worry if you need to sweep the sky with a pair of binoculars to track it down – you'll find you can go back to it easily by making a mental note of which trees or chimneys on the skyline it is directly above.

By the end of our observing period, Mercury will have moved a lot closer to the Sun in the sky and will be much harder to see. By 1 December it will be rising only half an hour before the Sun and will be lost in its glare. But before then, be sure to set your alarm early for the mornings of 10 and 11 November, when Mercury will be just a degree or so away from Mars in the predawn sky.

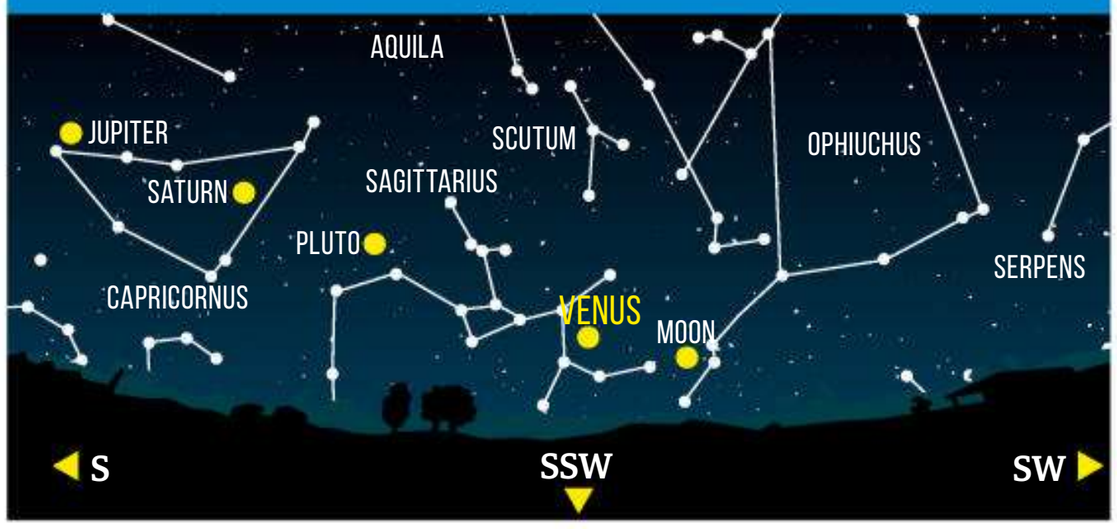
MARS 07:00 GMT on 11 November



Constellation: Virgo **Magnitude:** +1.7 **AM/PM:** AM

This will be another very challenging month for Mars observers. At the start of our observing period the Red Planet will be a morning object, rising not long before the Sun, and at just brighter than second magnitude it will be lost in the glow of the predawn sky. But as the days pass Mars will slowly pull away from the Sun, becoming easier to see.

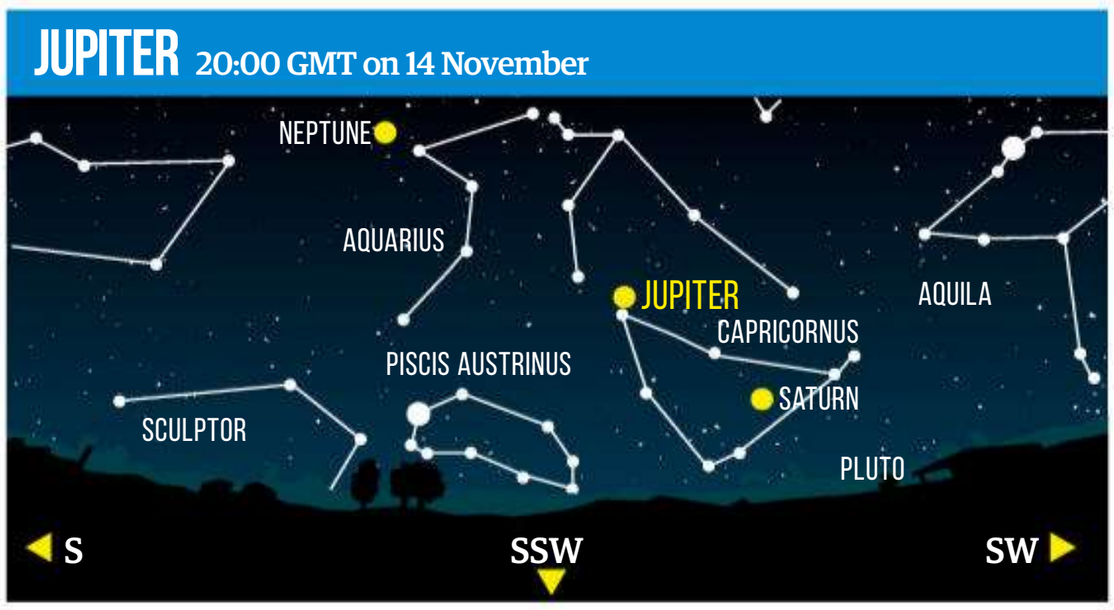
VENUS 17:00 GMT on 7 November



Constellation: Sagittarius **Magnitude:** -4.5 **AM/PM:** PM

Although Venus will be low in the sky throughout the month, it will be an easy naked-eye object visible after sunset. As the month progresses it will get easier to see and brighter, too, becoming a true 'evening star' by the start of December. Despite its brightness, it might be challenging to see if there are any hills, trees or tall buildings on the horizon to your southwest.

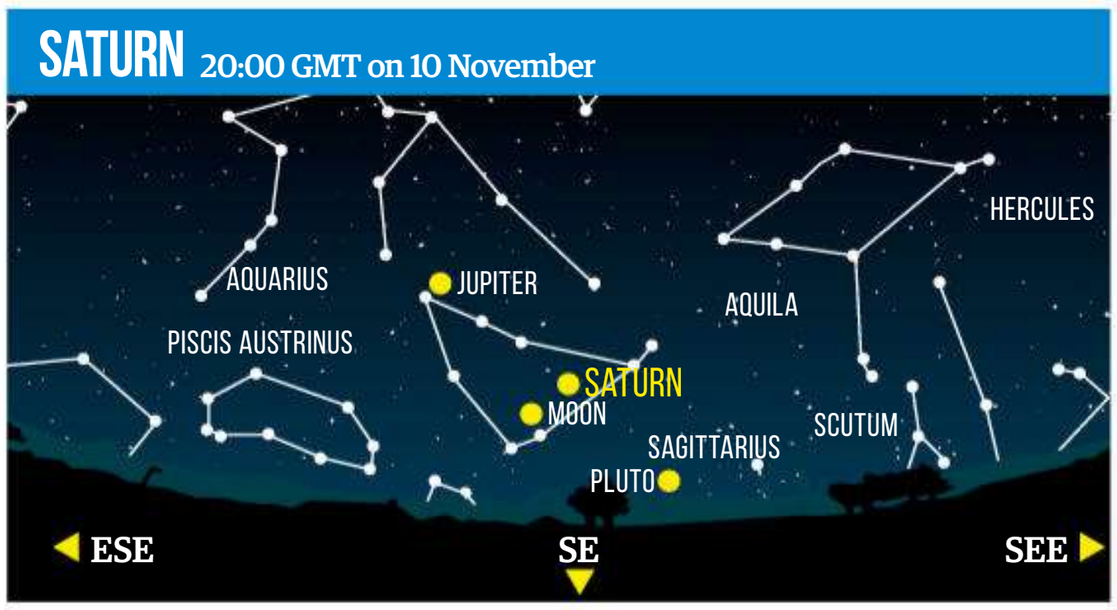
JUPITER 20:00 GMT on 14 November



Constellation: Capricornus **Magnitude:** -2.5 **AM/PM:** PM

Gas giant Jupiter will be a striking sight in the evening sky throughout this month. It will be easily visible to the naked eye as a bright, blue-white 'star' above the southern horizon that comes out as soon as the sky begins to get dark. At the start of November Jupiter will be visible from sunset until around midnight, giving planet-watchers lots of time to observe it.

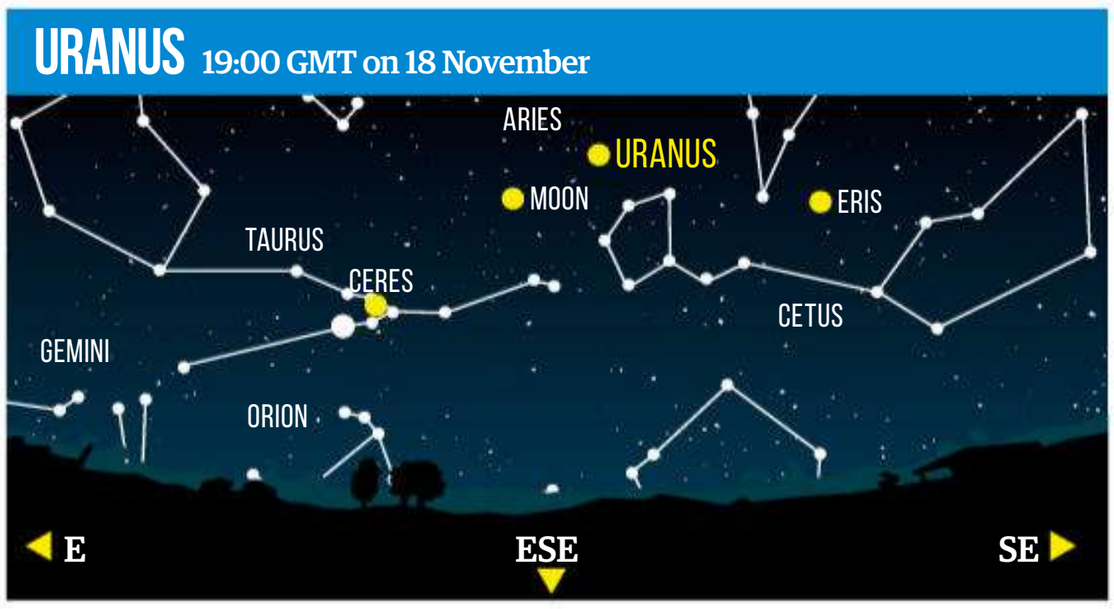
SATURN 20:00 GMT on 10 November



Constellation: Capricornus **Magnitude:** +0.6 **AM/PM:** PM

Saturn will be easily visible to the naked eye throughout the month, low in the south as soon as the sky begins to darken after sunset. It will look like a bright, yellow-hued star, shining to the right of much brighter Jupiter. You won't confuse the two, as Jupiter will have a much more vivid blue-white colour.

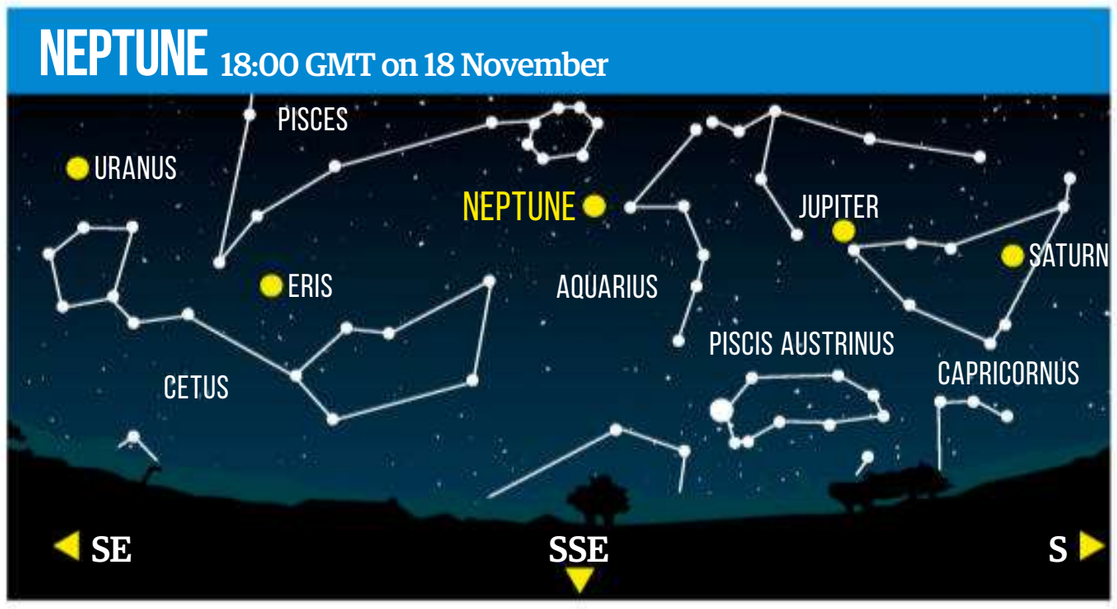
URANUS 19:00 GMT on 18 November



Constellation: Aries **Magnitude:** +5.6 **AM/PM:** PM

Uranus looks just like one star among many stars of the same brightness. If you have a pair of binoculars they will make this faraway ice giant easier to see because they will enhance its pale-green colour. This month Uranus will be visible all night, highest in the south around midnight. The almost-full Moon will blaze beneath on the evening of 18 November.

NEPTUNE 18:00 GMT on 18 November



Constellation: Aquarius **Magnitude:** +7.9 **AM/PM:** PM

Neptune is the farthest planet from the Sun, so is too faint to be visible to the naked eye, even if you're looking for it under the most perfectly clear dark sky with no Moon and no light pollution. If you have a pair of binoculars, they will help you find it in the sky, but even then it will only look like a very tiny, blue-green star surrounded by many other stars.

© NASA

MOON TOUR

MARE CRISIUM (SEA OF CRISES)

Find a huge impact basin on the Moon, even without a telescope

If a prize was ever awarded for the 'easiest feature to find on the Moon', it would surely be given to Mare Crisium, the Sea of Crises. It's so big, so obvious and so well-placed that it actually takes a lot of effort to miss it. Even if you know absolutely nothing about the Moon and its surface features, you'll have seen Mare Crisium many times already.

It was named in 1651 by astronomer and lunar cartographer Giovanni Riccioli after being known previously as 'the Caspian Sea', among other things. Mare Crisium doesn't just have a special place in lunar science; it's featured heavily in science fiction, too. It was the setting for sci-fi master Robert Heinlein's classic story *The Moon is a Harsh Mistress*. It was also the setting of Arthur C. Clarke's story *The Sentinel*, which inspired the film *2001: A Space Odyssey*.

In real life, the lava plain has had no boots walk upon it so far. However, Mare Crisium has had several robotic visitors. In 1969 the Russian Luna 15 probe crashed there. In August 1976 the Luna 24 probe, also Russian, landed successfully on the sea, collected precious samples of rock and brought them safely back to Earth for analysis.

If you've ever looked at a full Moon, or even a first quarter Moon, you'll have noticed a small, dark oval shape at the top right of its disc, up at about the one o'clock position. It's really obvious through a small telescope, or just the smallest pair of binoculars, but even your naked eye is powerful enough to pick it out.

Mare Crisium is a vast plain of ancient, dark lava which covers the floor of the Crisium Basin. In fact, calling it 'vast' doesn't do it justice. Mare Crisium is more than 550 kilometres (342 miles) wide, covering an area of roughly 176,000 square kilometres (68,000 square miles). It was formed between 3.9 and 4.5 billion years ago when an asteroid struck the Moon so hard it didn't just leave an enormous hole, but flooded it with a vast pool of melted rock and debris. This spread across its floor, cooled and set, leaving behind the dark 'sea' we see today.

TOP TIP!

Mare Crisium is at its most obvious on or around full Moon, when it is clear to the naked eye.

Mare Crisium will start to become visible on the evening of 8 November, when sunlight starts to pour across it from the east. On that date the Moon will be what many people call a new Moon – a lovely slender crescent, low in the west as dusk deepens. On this evening you'll only be able to see the most eastern part of the feature. It will take just over 24 hours for the whole of the feature to be lit by the Sun, so by the evening of 9 November the whole of the sea will be visible, looking like a dirty grey-black thumbprint on the bright, clean face of the Moon.

Mare Crisium will remain fully illuminated until the evening of 23 November, when darkness will start to creep across the sea from the east. If you have a telescope, this will be a good time to use it to look for the small, young craters spattering the sea, including 19-kilometre (11-mile) wide Peirce and 23-kilometre (14.3-mile) wide Picard.

If you look at Mare Crisium through a high-magnification eyepiece at this time, you might also be able to see other more subtle features on the lava-flooded floor, such as the ghostly, raised outlines of the craters Yerkes and Lick, which were filled and almost covered by lava when the basin flooded. Under really good viewing conditions you might also see low ridges of ancient rock here and there on the lava plain – lava ripples that set in place, and today look like hairs on a freshly painted wall.

Mare Crisium will have vanished from view on 25 November, plunged into the freezing darkness of the long lunar night once more, not to return to view again until the evening of 8 December.

NAKED EYE & BINOCULAR TARGETS

Glittering giants and spectacular star clusters are easy finds in the night sky

PERSEUS

TAURUS

ORION

1 Ain and Amateru
Shining close to Aldebaran, magnitude +3.5 orange giant Ain is a member of the Hyades cluster. Almost 150 light years from Earth, it's orbited by a massive exoplanet that dwarfs Jupiter. Discovered in 2007, the planet was christened 'Amateru' by astronomers in 2015.

2 The Pleiades (Messier 45)
One of the prettiest and brightest star clusters in the sky, M45 is also known as the Pleiades, or the 'Seven Sisters', because seven of its 500 or so stars can be seen with the naked eye. It appears wider than four full Moons in our sky and lies 430 light years from Earth.

3 The Hyades (Caldwell 41)
This distinctive V-shaped star cluster has five stars bright enough to be seen with the naked eye, but actually contains between 300 and 400 stars. It has been known since prehistoric times and can be seen in cave paintings thousands of years old.

4 Crab Nebula (Messier 1)
The ghostly remains of a giant star that exploded in a massive supernova explosion in 1054, it was nicknamed the Crab Nebula because of its appearance through a telescope. Too faint for the naked eye to see, it is best viewable through a pair of binoculars as a tiny smudge.

5 Aldebaran (Alpha Tauri)
This magnitude +0.8 star is the 14th-brightest in the sky. An orange giant 44 times our Sun's diameter, it lies 65 light years from Earth and represents the eye of Taurus, the Bull. Despite appearances, it's not a member of the Hyades cluster.

The Seagull Nebula (IC 2177)

DEEP SKY CHALLENGE

TOUR BEYOND THE ORION NEBULA

Track down some of winter's lesser known wonders on the next clear and chilly night

Just as it's easy for us to return to the same 'celestial celebrities' night after night during the summer months – the Ring Nebula, Messier 13 and Messier 51 all repeatedly draw the eye away from other things – the deep-sky observer's winter comforts are the bright, swirling clouds of the stunning Orion Nebula and the glittering spectacle of the Pleiades. But there are many other objects in the winter sky just as – if not more – deserving of our attention. Given that November nights are often beautifully clear and cold, this is a good time to wrap up warm, head out and track down some of the objects that are often overlooked in favour of their brighter, brasher neighbours.

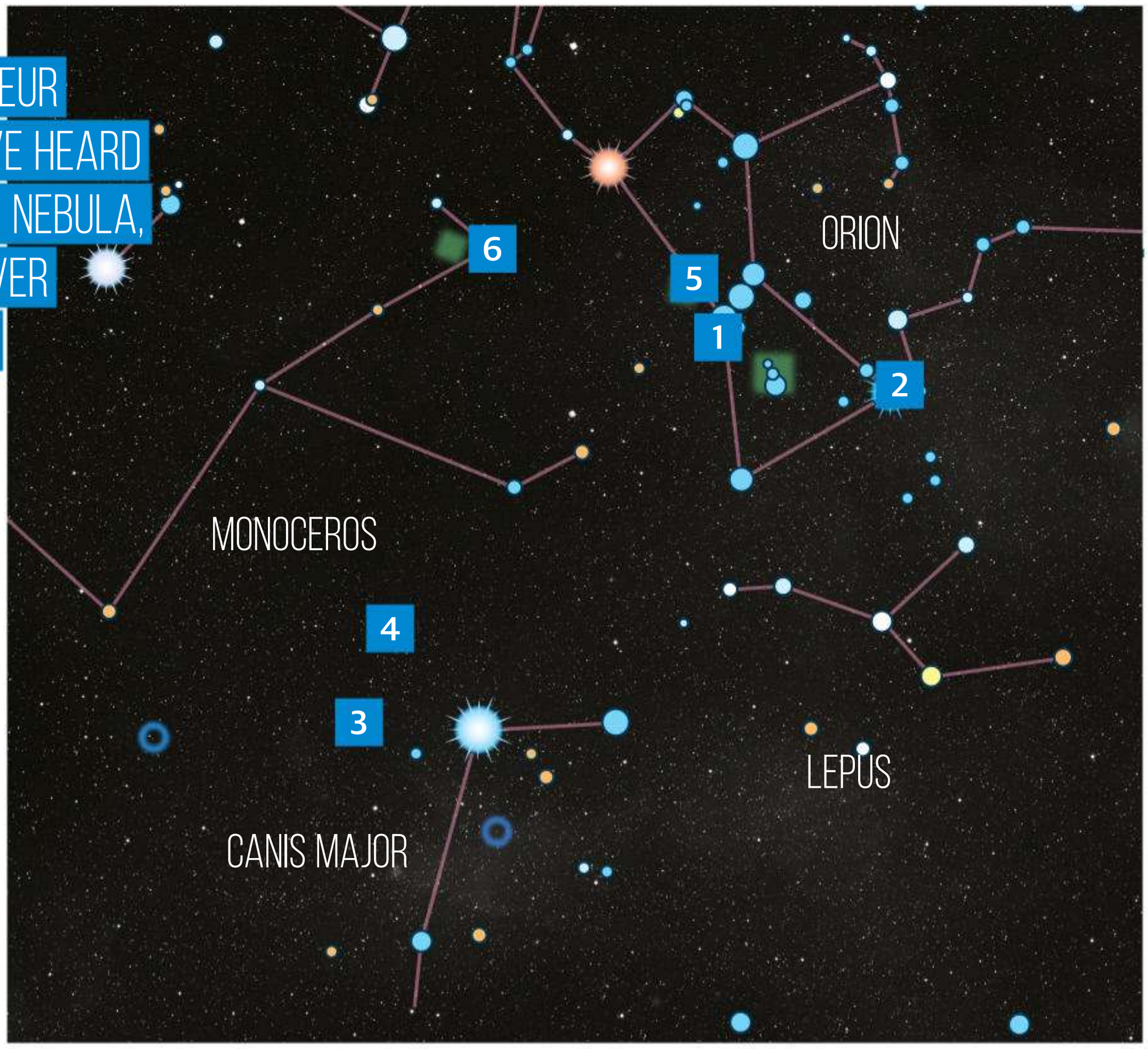
While most amateur astronomers have heard of the Horsehead Nebula, very few have ever actually seen it. Although photographs suggest it's a very dramatic-looking object – a bold knight chess piece silhouetted against a cherry-red curtain of light – in all but the largest telescopes it's little more than a dark notch in a slightly lighter area. Likewise, the Rosette Nebula can be seen on every wide-field photo taken of Orion, looking like an orange flower to the left of Betelgeuse, but its low surface brightness and wide area mean it's little more than a puff of smoke with a star-spangled centre through most telescopes.

Witch Head Nebula (IC 2118)

© NASA

Source: Wikipedia Commons © Azhikerdude

"WHILE MOST AMATEUR ASTRONOMERS HAVE HEARD OF THE HORSEHEAD NEBULA, VERY FEW HAVE EVER ACTUALLY SEEN IT"



1 The Horsehead Nebula (Barnard 33)

This dark nebula looks strikingly similar to a horse's head in long exposures, but you'll need a large telescope, a very dark sky, perfect seeing and maybe even a filter if you're going to see it.

2 The Witch Head Nebula (IC 2118)

Illuminated by the icy-blue glare of nearby giant star Rigel, this tenth-magnitude cloud of gas looks like the face of a crooked-nosed witch through large-aperture telescopes.

3 Thor's Helmet (NGC 2359)

Finding this 11th-magnitude nebula is a huge challenge. Observing under a dark sky, a large telescope fitted with a nebula filter will show hints of filaments and mottling within it.

4 The Seagull Nebula (IC 2177)

If you use averted vision looking at this tenth-magnitude nebula through a large telescope's widest field eyepiece, you might see it has a bright 'head' and faint, outstretched 'wings'.

5 Messier 78

Although a small telescope will easily show this nebula's bright centre, larger instruments and high magnifications are needed to see subtle detail at its edges.

6 The Rosette Nebula (NGC 2237)

The Rosette Nebula is bright and colourful in photos, but visually it appears as a vague, grey-white smudge through large-aperture telescopes on Moon-free nights.

The Horsehead Nebula (Barnard 33)

Source: Wikipedia Commons © Stephanh

THE NORTHERN HEMISPHERE

The constellations of autumn are slowly being pushed from our night skies by those of winter

Along with the planetary members of our Solar System making their way across the ecliptic, plenty of deep-sky objects – including a selection of elliptical and spiral galaxies – are there for astronomers to enjoy through to early December evenings. The constellations of winter have started to make themselves known: Orion, Cetus, Canis Major and Taurus in particular make a dramatic entrance in the darker skies, appearing to push the autumn star patterns out of view, but still providing the perfect opportunity to observe a selection of targets across two seasons. The Orion Nebula (M42) is easy to spot with the naked eye from a dark-sky site, or with binoculars and telescopes in light-polluted areas.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

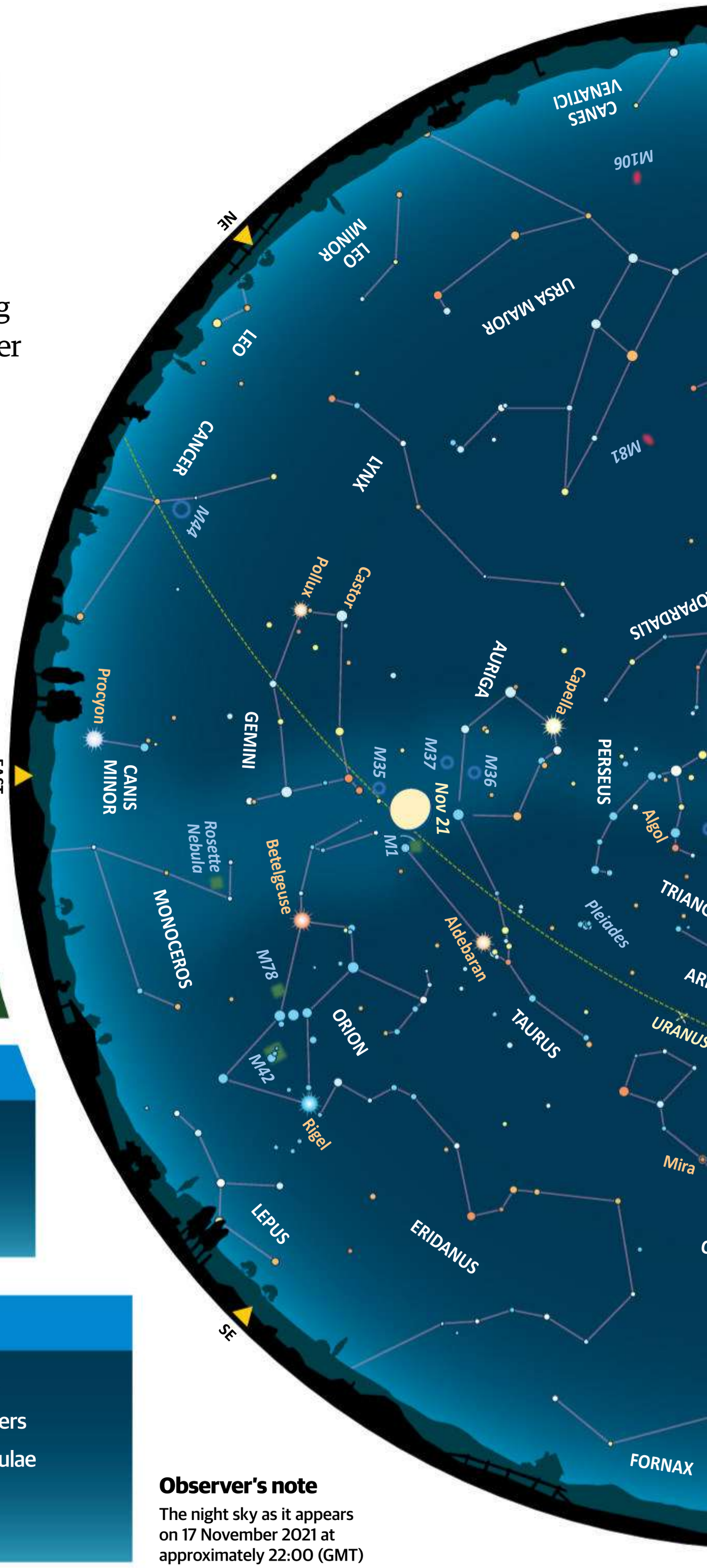
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- G
- A
- K
- F
- M

DEEP-SKY OBJECTS

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies

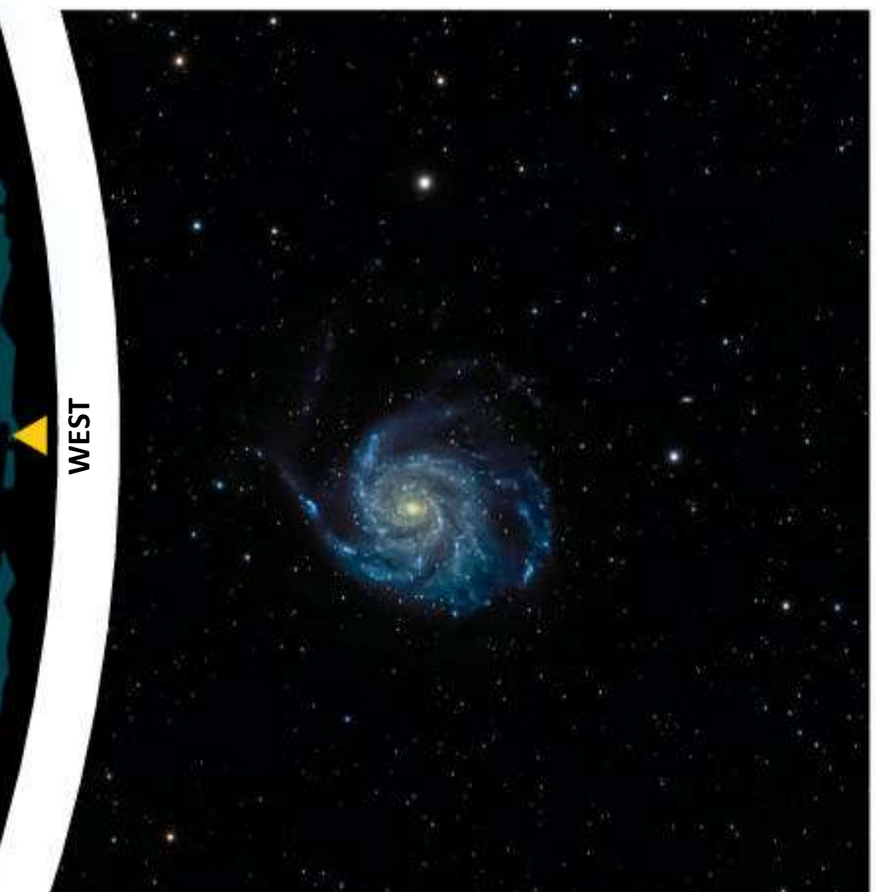


Observer's note

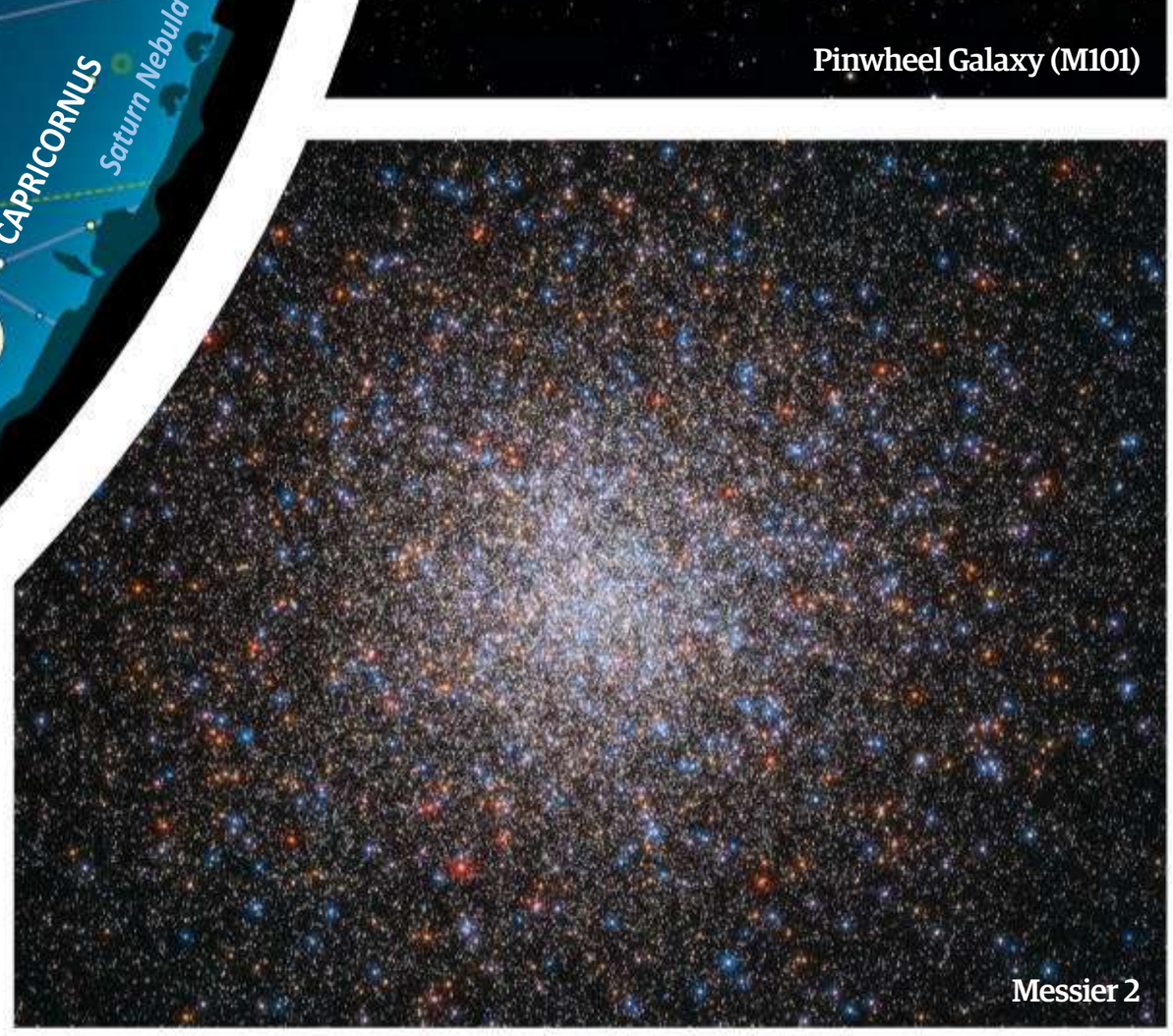
The night sky as it appears on 17 November 2021 at approximately 22:00 (GMT)

Andromeda Galaxy (M31)

© Getty


Pinwheel Galaxy (M101)

© Getty


Messier 2

© ESA/Hubble & NASA

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

Dave Eagle

Location: Higham Ferrers, UK

Telescope: Sky-Watcher 190MN Maksutov-Newtonian, 80mm refractor

"I have always held a real fascination for the night sky after a false start thinking that the Pleiades was the Big Dipper, and I eventually learned the constellations. After a lull in my teenage years, and bringing up a family, the appearance of Halley's Comet re-ignited that passion, which has since burned so brightly.

"I love observing trips with like-minded friends to darker sites like Tenerife, away from most light pollution, where the stars, Milky Way and even the zodiacal light are stunning. I am a regular attendee of the Autumn Equinox Star Party at Kelling, which if the skies are clear provides some great observing or imaging."

Above: C/2013 R1 (Lovejoy)

Right: Orion Nebula (M42)

"THE APPEARANCE OF HALLEY'S COMET RE-IGNITED THAT PASSION"

Left: Craters and dark seas on the lunar surface

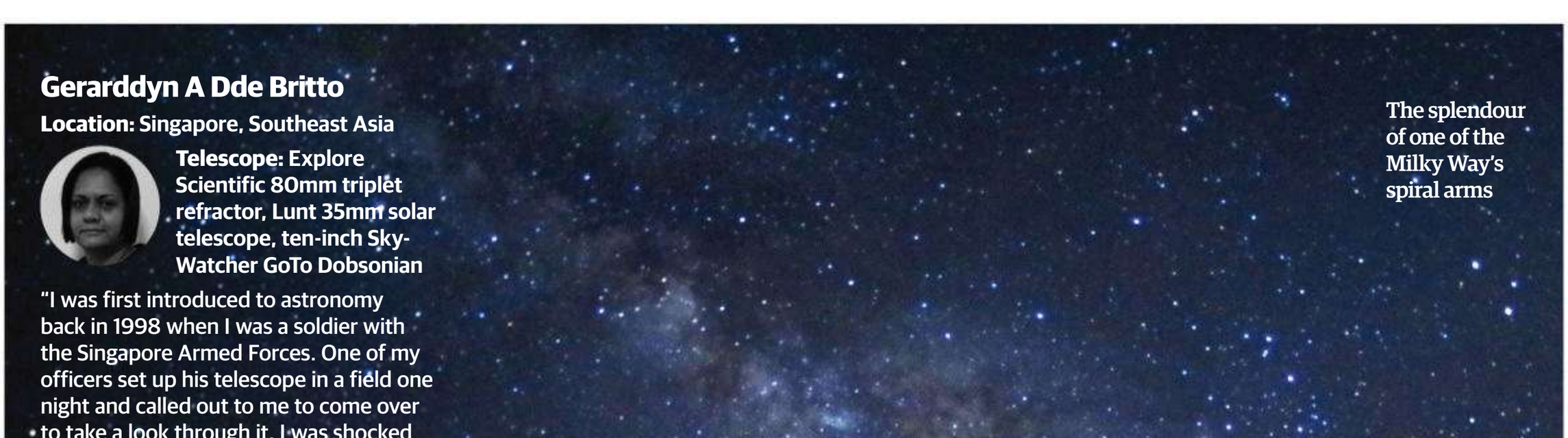
Alastair Woodward

Location: Derby, UK

Telescope: Sky-Watcher Explorer 150P and Sky-Watcher 200P Skyliner Dobsonian

"My passion for science and technology began at a young age, and led me to study computing at university. While always fascinated by the night sky – in particular the Moon – it wasn't until the passing of my father that I started to think further about the existential questions of life. Where better to gain a better insight of our being, history and place in the universe than examining, exploring and photographing the night sky?

"Given the UK climate, I find that being able to set up at a moment's notice is crucial, so visits to dark sites haven't been as frequent as I like. Instead, my east-facing garden is usually the spot for both my visual observations and photographs."



The splendour of one of the Milky Way's spiral arms

Gerarddyn A Dde Britto

Location: Singapore, Southeast Asia

Telescope: Explore Scientific 80mm triplet refractor, Lunt 35mm solar telescope, ten-inch Sky-Watcher GoTo Dobsonian

"I was first introduced to astronomy back in 1998 when I was a soldier with the Singapore Armed Forces. One of my officers set up his telescope in a field one night and called out to me to come over to take a look through it. I was shocked to learn that I was looking at the planet Jupiter and its four Galilean moons: Io, Ganymede, Callisto and Europa. I never thought that I would actually see a planet with my own eyes. I was so fascinated that night that the very next day I purchased a Celestron 60mm refractor – my first telescope. That telescope never left my side until the year 2000, when my career got the better of me.

"Many years later in 2013, I was re-introduced to astronomy when I chanced upon a few enthusiasts. I fell in love with astronomy all over again, and this time with the internet, I was able to reconnect and understand the objects I was seeing a lot more.

"After some time, I started using my camera mobile handset to capture the Moon through my five-inch telescope, and before I knew it I was learning how to do astrophotography."

REVIEW

STARLIGHT APP

A great stargazing app for learning the basics, but it doesn't offer much depth beyond what you'll find with a simple Google search

Reviewed by Jamie Sharp

STARGAZING APP ADVICE

Cost: Free (£1.69 / $1.99 ad-free upgrade)

From: Google Play and Apple App Store

Version: 3.2.6

BEST FOR...

£ SMALL BUDGETS

! BEGINNER

STARS & CONSTELLATIONS

PLANETS

MOON PHASES

FAMILIES

Since the first iPhone graced our palms, we've looked to the App Store in search of something that can help us indulge our need to analyse the sky and delve deep into the science of the universe around us. Unfortunately, while many applications offer you a chance to see incredible images taken with military-grade optics, none of that helps you work out what you're seeing when you look into the night sky. Even with a pair of the best binoculars or a good telescope, between shaky hands and the growing bits and pieces of space junk floating around the Earth, it can be hard to work out what you're looking at.

Starlight is an app that goes a long way to help anyone shift from being a complete novice with an eagerness to learn into a knowledgeable aspiring astronomer that can point out planets using nothing more than the brightness of the stars and the familiarity of their positions. While it doesn't provide you with everything you might want, it's filled with encyclopedic information on the basics, and that's a perfect starting point for anyone.

Starlight is a deceptively simple app: it provides you with an augmented-reality (AR) overlay of the world around you. Once set up, you can open it and see the stars around Earth regardless of the time of day. However, it's much better when used at night, because you can look at a star above you, move the app between you and that star and work out what its name is, the constellation it belongs to and dive into further information about it.

The best thing about Starlight is the fact that you can browse the sky for hours without needing to bend over a telescope, backwards with binoculars or lying down on the ground avoiding breathing in case you lose a star while you exhale. Instead, using the app is like taking a picture. Aim it where you want, tap the screen twice and you'll be reading about the star you're looking at within seconds. Calibration is also extremely straightforward. All you need to do is wave your phone around in a figure of eight pattern a few times for the app to work out where it is and start accurately showing you what the stars you're looking at are called. Each time we tested the app, it picked up the stars we could see in the night sky perfectly, aligning precisely with what we could see with our own eyes.

Starlight brings up the names and shapes of constellations as you move it around. Helpfully, it fills in those shapes so that you can see what Taurus, Orion and many more constellations are supposed to look like. The brightest stars and planets in the sky are also clearly named, with Jupiter, Venus and Saturn chief among them.

If you want to learn more about a constellation, star or planet, you can tap it to bring up an information icon that will open a new page for you to read through. Unfortunately, Starlight doesn't offer an exhaustive database of facts on everything in the sky. Still, it does have a direct Wikipedia page link for anyone hoping to understand a particularly fascinating point in the sky.

SkyView is another app that does something similar, though it outperforms Starlight in some areas. For example, SkyView allows you to track spacecraft such as satellites, disused rockets and even the International Space Station as it orbits the planet in addition to the stars in the sky. It feels like a fuller experience, and considering that SkyView is free, we think Starlight should have this feature implemented.

A fantastic feature is that the pages you open overlay the screen, so you can see the sky moving in the background while you read. There are also images to help demonstrate what you might be looking at – whether it's Uranus or a far-off blue star that we have no decent photos of.

If you don't fancy looking like a bit of a lunatic moving your phone around like you're taking pictures of the sky, then you can turn the gyroscope off and use your fingers to scan the sky instead. You can see an entire sphere making up the Northern and Southern Hemispheres, so you'll be able to track every star in the sky regardless

Left: The red-light mode is perfect for when you're out observing

Jupiter
the Fifth Planet
Gravity
2.528 g
Surface Temperature
165 K
Axial Tilt
3.13°
Equatorial Radius
71492 km
Orbital Period
4332 days
Mass
1.8982×10²⁷ kg
Jupiter is the fifth planet from the Sun and the largest planet within the Solar System. It is a gas giant with mass one-thousandth that of the Sun but is two and a half times the mass of all the other planets in our Solar System combined. Jupiter is classified as a gas giant along with Saturn, Uranus and Neptune. Together, these four planets are sometimes referred to as the Jovian or outer planets. The planet was known by astronomers of ancient times and was associated with the mythology and religious beliefs of many cultures.
Search
Andromeda
the Princess, currently above horizon
Antlia
the Air Pump, currently below horizon
Apus
Bird of Paradise, currently below horizon
Aquarius
the Water Bearer, currently above horizon
Aquila
the Eagle, currently above horizon
Ara
the Altar, currently below horizon
Aries
the Ram, currently above horizon
Auriga
the Charioteer, currently below horizon
Boötes
the Bear Driver, currently above horizo
Caelum
Constellations
Solar System
COMA BERENICES
Vindemiatrix
VIRGO
Moon
Spica
LIBRA

of your location. You can also zoom in to a degree so that you can analyse much dimmer stars that are blocked out by light pollution or the light from their much closer neighbours. The only downside is that most of the smaller stars are set dressing – you can't tap on them and learn interesting facts about them. The closest you can get is tapping on a constellation and visiting its Wikipedia page to find out which stars make it up.

Starlight is a brilliant starting point for anyone hoping to learn more about the night sky. However, it's far from a comprehensive guide... more of a beginner's guide to the galaxy. You'll learn about the constellations, scrub up on your knowledge of the planets, including Pluto, and get a taste for what lies beyond. That's all you'll get though.

We didn't expect the universe, but we did expect to learn a bit more about it, and maybe even have a few pages of information on each celestial body based on a compilation of reliable sources. Instead, we're referred to Wikipedia if we want to learn more than the basics. However, the overlay it provides helps immerse you in the stars, and the original images and artwork bring the constellations to life.

Anyone that wants to learn more about the universe around them and start getting into stargazing will find a helpful resource in Starlight. However, those with the basics covered should look for something more advanced.

Top: Basic information on brighter stars and planets is included

Left: The app can be controlled by hand or with your device's gyroscope

FOR

- AR overlay that mirrors the night sky
- Original artwork for constellations
- Some stars have vast amounts of information to read through

AGAINST

- Refers you to Wikipedia for reading on most stars
- Doesn't contain human-made objects like the ISS
- Too basic for anyone with pre-existing knowledge

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From: esaspaceshop.com

1 Celebrate the future of lunar exploration with this sweatshirt – available in black or navy – from the European Space Agency. The design incorporates the Orion spacecraft, which will be used on NASA's Artemis missions to the Moon. The sweatshirt uses calligraphy to depict Orion's trail around the Moon, as well as minimalist crater details. The unisex sweatshirt is made from 80 per cent ring-spun cotton and 20 per cent polyester and is available in sizes S, M, L, XL and XXL. Each sweatshirt is made to order and crafted by hand in Italy.

FOR THE FESTIVE SEASON

PLANET-SHAPED CHRISTMAS DECORATION

Cost: £4.95 (approx. $6.75)

From: thegiftedfew.com

2 It's (almost) that time of year again! Add a splash of cosmic magic to this year's Christmas tree with this delightful Sass & Belle Saturn-shaped ornament. The ultramarine glass bauble is adorned with gold stars and a sparkly planetary ring system. Measuring eight centimetres (3.1 inches) in diameter, this exquisite bauble will effortlessly complement any festive scene. A variety of other space-themed Christmas baubles are available from the Gifted Few, including a set of five Moon phase baubles and a set of four mini-planets.

FOR WINTER OBSERVING

COOWOO LENS HEATER WITH TEMPERATURE REGULATOR STRIP

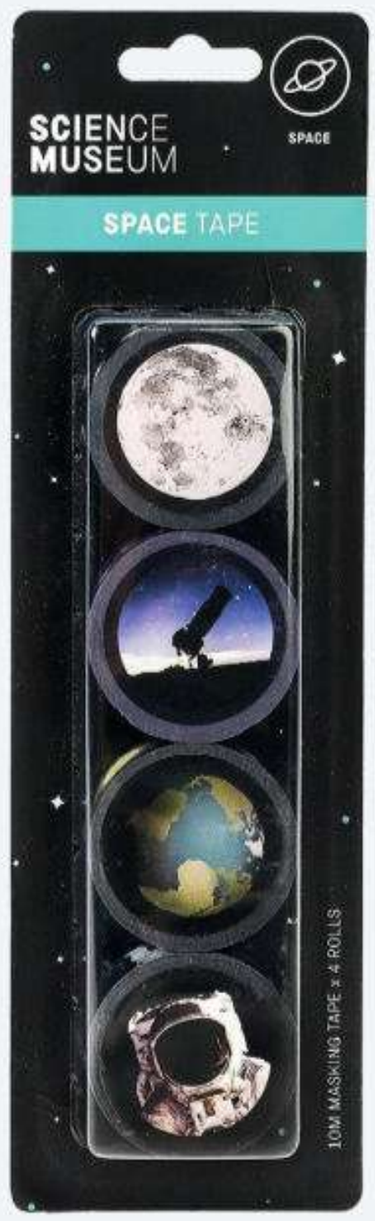
Cost: £19.99 / $19.99

From: Amazon

3 A simple neoprene band that slips around your lens, with a USB plug for taking power from a rechargeable power pack – or a phone charger, if you have an extension cable that reaches far enough – this lens heater will keep the dew off your lens for as long as its power source holds out. Suitable for lenses up to 41 centimetres (16 inches) in circumference, the band is secured with Velcro.

5

6



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FOR FUN

SCIENCE MUSEUM SPACE TAPE

Cost: £9.95 (approx. $13.60)

From: shop.sciencemuseum.org.uk

4 Take your gift-wrapping skills or scrapbook creations to the next level with this set of space-themed tapes. With four designs to choose from in the pack – phases of the Moon, constellations, planets and astronauts – this washi tape is guaranteed to make a statement. The set contains four ten-metre (33-foot) tape rolls, each 2.3 centimetres (one-inch) wide.

FOR YOUR HOME

PLANET CEILING FITTING

Cost: £40 (approx. $54.60)

From: dunelm.com

5 Liven up your living space with this charming ringed planet ceiling light fitting. The modern matte-grey steel frame is accompanied by a white glass shade and holds a Small Edison Screw E14 bulb (not included with the fixture). The fitting is 34.5 centimetres (13.6 inches) in height, 45 centimetres (17.7 inches) wide, 13 centimetres (5.11 inches) deep and weighs 0.88 kilograms. This is an ideal accessory for space-loving kids and adults alike and will make an interesting focal point of any room.

FOR YOUR BEDROOM

MOON DUVET COVER SET WITH REUSABLE FABRIC BAG

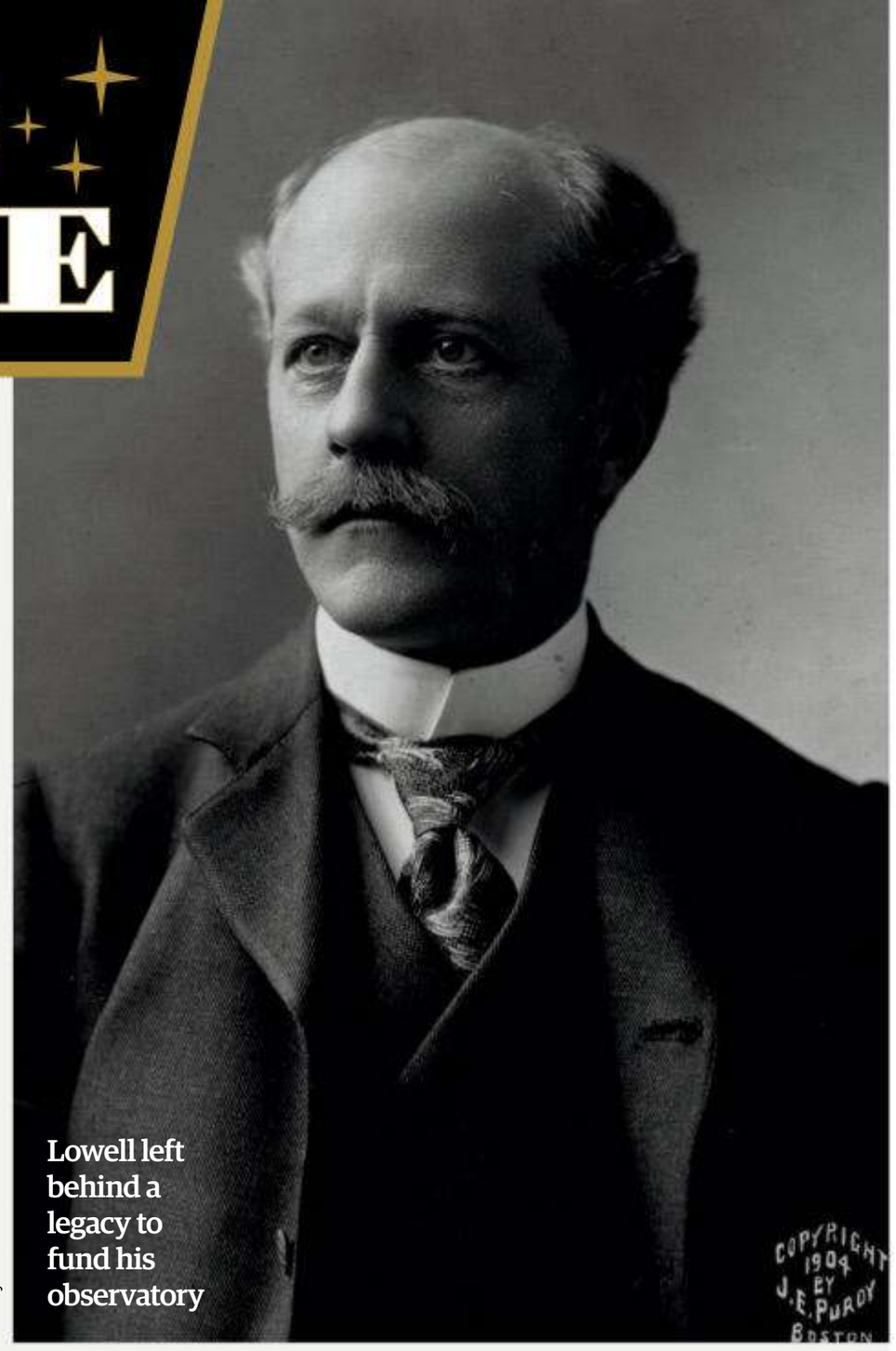
Cost: From £30 (approx. $41)

From: Urban Outfitters

6 Settle down for a cosy night in with this enchanting celestial-inspired duvet set. Available in single (includes one pillowcase), double (includes two pillowcases) and king (includes two pillowcases), this 100 per cent cotton bed set can be machine washed. Urban Outfitters is trying to reduce the amount of cardboard and plastic packaging they use for their products, so the bedding is packaged in a matching, reusable fabric bag – how handy!

PERCIVAL LOWELL

Lowell's attraction to Mars led him into a love affair with worlds beyond our own



Lowell left behind a legacy to fund his observatory

© Getty

From the study of Mars and the prediction of Pluto to the building of the observatory that bears his name, Lowell dove headlong into astronomy. Lowell was born on 13 March 1855. He attended Harvard University, graduating in 1876 with a degree in mathematics. After college, Lowell worked for his family's textile business, and in 1883 he served as a foreign secretary as part of the first Korean diplomatic mission.

In the 1890s, Lowell learned about the discovery of 'canalis' on Mars by Italian astronomer Giovanni Schiaparelli. Schiaparelli was reporting on channels crisscrossing the surface of the Red Planet, but the English mistranslation of 'canals' fired up excitement in Lowell. Determined to be prepared for Martian opposition in 1894, Lowell decided to build an observatory. He selected Flagstaff, Arizona, where the high altitude, thin atmosphere and remote location would give him a good view of the planet. He built Lowell Observatory on Mars Hill, where he sketched the surface of Mars as it drew closer. What he found – or thought he found – electrified him.

Soon after his observations, Lowell announced his discovery of canals and oases on Mars. The long straight lines he sketched and described were not natural features, but channels of water cut by a dying civilisation, he claimed. The idea of intelligent beings on Mars quickly caught on in the public imagination, fuelled by Lowell's enthusiasm. He delivered a series of lectures on the canals and the society that constructed them, as well as writing three books – *Mars*, *Mars and its Canals* and *Mars as the Abode of Life* – and a slew of articles on the Red Planet.

But the canals Lowell insisted he saw couldn't be observed by other scientists; he claimed that such observations depended heavily on viewing conditions. But Lowell's canals were definitively disproven by NASA's Mariner missions. In 1965, Mariner 4 took close-up images of Mars, and in 1971, Mariner 9 mapped it. No canals were found.

Lowell also mapped features on Venus, though later observations revealed none could be seen through the planet's thick atmosphere. It's most likely the features Lowell spotted on both bodies were the result of an optical illusion caused by his telescope. Lowell also calculated that variations in the orbits of Neptune and Uranus were caused by a ninth planet, which he dubbed Planet X. In 1906, Lowell put his observatory to work searching for the missing planet.

Lowell had suffered health problems over his lifetime, and on 12 November 1916, at the age of 61, he died of a cerebral haemorrhage at Mars Hill. Lowell left behind a fortune to fund the observatory's continued search for Planet X. His widow contested this, and a legal battle ensued that depleted most of the funds. Nevertheless, the search for the planet continued.

In 1930, an astronomer employed at the observatory, Clyde Tombaugh, noticed movement in photos taken at different times. Using an instrument known as a blink comparator, he flipped rapidly between two photos of the sky, checking for movement between them. On 13 March that year, a new planet was announced: Pluto. The name was chosen because the cold, distant planet may well have resembled the home of the Greek god of the underworld. The symbol for Pluto encompasses Lowell's initials. Pluto, reclassified in 2006 as a dwarf planet, is too small to have impacted the orbit of Uranus and Neptune. In fact, accurate measurements of the icy gas giants showed that their orbits never really shifted, making Lowell's measurements completely coincidental.

Although none of Lowell's theories ultimately panned out, his enthusiasm provided a significant boost to the public's imagination when it came to Mars. His search for Planet X led to the discovery of Pluto, and the construction of Lowell Observatory led to a number of significant scientific findings.

All About Space

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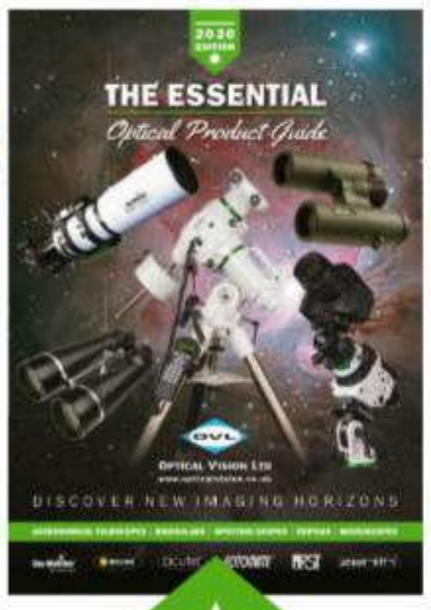

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